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ABSTRACT

Landforms, vegetation, water bodies, climate and solar radiation can be analyzed and used to design an energy-conserving landscape and horticulture operation. Accordingly, this course instructor's manual covers the use of the elements of the environment to make landscaping and nursery design and operation more energy-efficient. Five sections comprise the guide: (1) background material on site analysis, which is the course's central focus; (2) information about designing energy-conserving landscapes; (3) a section on greenhouse orientation and design for solar energy use; (4) guidelines for conserving energy in nursery design and operation; and (5) a set of site maps and suggested ways to use them within a classroom to apply principles covered in previous portions of the manual. The guide's five sections can be used to teach separate courses on landscaping, greenhouses, and nurseries. (Author/WB)

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Landscape Design and Nursery Operation for Energy Conservation

Course Outline and Instructional Materials

Program Development
Dept. of Community Colleges
Raleigh, N.C. 27611

SE 035 050

LANDSCAPE DESIGN AND NURSERY OPERATION FOR ENERGY CONSERVATION

by

Richard C. Bell
and
Dennis Glazener

Winter, 1980

for

Energy Conservation Curriculum and Short Course Project #8208, Occupational Program Services (formerly Program Development Section), North Carolina Department of Community Colleges

Project Director	Coordinator
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FOREWORD

This instructional manual was prepared by the Department of Community Colleges as a part of its plan to provide courses on energy conservation for curriculum and extension programs. The purpose of this manual is to teach the use of the elements of the environment to make landscaping and nursery design and operation more energy efficient. Landforms, vegetation, water bodies, climate and solar radiation can be analyzed and used to design an energy conserving landscape and horticulture operation. Individuals who complete these courses will have a better understanding of energy conservation techniques and skills that can be used to reduce the consumption of scarce energy sources.

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Instructors' Section

This manual consists of five sections.

CORE - How to make a site analysis in preparation for energy conserving landscaping, construction or setting up of a nursery operation.

Upon completion of this section, the student will be able to do the following:

1. Make a site analysis of a given site.
2. Prepare a slope map given a topographical map of a site.
    a. Calculate percentage of slope given rise and run of contour intervals on a map.
    b. Calculate horizontal distance between contours on a slope map.
    c. Analyze slope map to determine location of three types of slopes: good, workable, and those requiring excessive grading.
3. Locate soil survey through U.S. Conservation Service for given site and prepare soil map for site.
4. Prepare vegetation map of site.
5. Prepare architectural map of site.
6. Prepare hydrological map of site.
7. Calculate amount of solar radiation for a given month falling on horizontial, vertical and certain inclined surfaces at a given latitude.
8. Plot skyline for a given site on a sun chart to determine obstruction to solar gain.

LANDSCAPING FOR ENERGY CONSERVATION - Application of site analysis to to plan energy conserving landscaping or alter present landscaping to make it more energy conserving.

Upon completion of this section, the student will be able to do the following:

1. Determine proper placement of a building on a given site in order to utilize solar gain.
2. Analyze a site to determine its positive and negative energy conserving features.
3. Analyze site and recommend planting or cutting of existing plants to utilize solar gain, alter humidity and deflect or channel winds.

ENERGY EFFICIENT GREENHOUSES - Orientation of greenhouses in relation to site and design of greenhouses as a passive solar heating/cooling system.

Upon completion of this section, the student will be able to do the following:

1. Determine proper orientation of a greenhouse on a given site in order to get maximum solar gain.
2. Calculate ideal angle of south wall and/or roof for maximum solar gain during a given month in a given latitude.
3. Analyze available or proposed greenhouse plans according to expandibility, spatial efficiency, insulation, glazing material and solar efficiency.
4. Given a solar greenhouse, can analyze heat collection and storage system according to types of passive solar systems: direct gain, indirect gain and isolated gain.

5. Calculate optimum area and thickness of a thermal storage wall given the floor area to be heated, average outdoor temperature and material to be used to construct wall.
6. Recommend appropriate insulation techniques for a given greenhouse, e.g., placement of vegetation, berming, use of vestibules, movable insulation, shade cloths, reflective films, etc.

NURSERY DESIGN AND OPERATION FOR ENERGY CONSERVATION - Design of a nursery and its operation or analysis of an existing operation to increase the energy efficiency of the operation.

Upon completion of this section, the student will be able to do the following:

1. Record existing natural conditions and resources of a given proposed nursery site.
    a. Determine location of access.
    b. Determine which vegetation can be used and should remain.
    c. Determine if existing structures can be salvaged or how to use them.
    d. Map slopes to determine drainage and suitable locations for development.
    e. Map path of sun taken across property during winter and summer.
    f. Calculate path of wind across property winter and summer in relation to existing windbreaks and need for wind protection.
2. Given a proposed nursery site and record of existing natural conditions and resources, can plan a nursery operation layout.
3. Can analyze existing nursery operation and design an energy conservation plan.

EXERCISES - A set of site maps and suggested ways to use them within a classroom to apply the principles discussed in the previous four sections.

The sections of this manual can be used to teach three separate courses on landscaping, greenhouse design and operation, and nursery design and operation or used to teach any combination of these three. The "Core" section is intended as a reference guide for all the courses or it may be taught as background material for the courses. The "Exercises" section is provided as instructional assistance material.

SUGGESTED REFERENCES

1. American Society of Landscape Architects Foundation. Landscape Planning for Energy Conservation. Reston, VA: Environmental Press Design, 1977.
2. Clegg, P. and D. Watkins. The Complete Greenhouse Book. Charlotte, VT: Garden Way Publishing, 1978.
3. Energy Division, North Carolina Department of Commerce. The Solar Greenhouse: A Guide to the Design, Construction, and Use of Solar Greenhouses for North Carolina Owners. Call toll free (800) 662-7131.
4. Foster, Ruth S. Homeowner's Guide to Landscaping that Saves Energy Dollars. New York: David McKay Company, Incorporated, 1978.
5. McCullagh, J. C. The Solar Greenhouse Book. Emmaus, PA: Rodale Press, 1978
6. Nearing, H. and S. Nearing. Building and Using Our Sun-Heated Greenhouse. Charlotte, VT: Garden Way Publishing, 1977.
7. Solar Greenhouse, DC 124 and Agricultural Uses of Solar Energy, DC 153. Two bibliographies available free from the National Solar Heating and Cooling Information Center. Call toll free (800) 523-2929.

Core

introduction

Since the discovery of fossil fuel, over a century ago, man has sought the solutions to his problems through a highly developed technology. Technology, like mankind, requires energy in order to function.

OBSERVATIONS:

1/ Mankind is dependent on technology.

2/ Technology relies on non-renewable energy.

3/ Non-renewable energy reserves are finite and wasteful.

4/ As energy reserves drop and demand increases, prices for remaining supplies escalate.

5/ Rising prices contribute to inflation and unemployment.

6/ Inflation and unemployment are problems.

CONCLUSIONS:

We are not solving our problems. The real problem lies in the reliance of technology on non-renewable energy. This means that either new sources of energy must be found, or that new ways of harnessing old sources must be created.

Science, physics and engineering will be instrumental in accomplishing the task of discovering and implementing new forms of energy. In the meantime, our remaining resources must be conserved. One way to accomplish conservation is to cut down on consumption. Another solution would be to devise methods of making more efficient use of present energy reserves.

Every living organism is dependent upon energy for survival. The earth lives on power supplied by natural systems of the universe. When combined, these systems, functioning as a whole, become self-perpetuating. All elements of nature share a symbiotic relationship, each one affecting the other. Without this integration there would be waste, and the system would cease to regenerate itself.

Technology, like a living organism, requires energy in order to function. Isolated from the forces of nature, technology becomes limited to a finite source of energy. Waste is an unfavorable aspect of nonrenewable systems. This waste not only causes environmental problems, but is extremely costly to monitor and control. Depending on nonrenewable energy is costly. As energy reserves drop and demand increases, prices for remaining supplies escalate. The true problem of the energy crisis in terms of buildings and utilities is not energy supply, but rather the method used in the application of these sources. Money is required to effect changes. Some methods of application are readily cost-effective. Others require greater amounts of time before the cost of the changes has cancelled itself through savings in energy expenditures.

This Core Course is an introduction to the Natural Systems of the Earth. If we are to successfully integrate our technologies with renewable resources, a full working knowledge of the relationships of these natural forces is essential. Through understanding we can begin to create dynamic systems which change in response to the environment, and ultimately to our own needs.

natural systems

I. Landform. A landform as it exists in nature consists of many natural systems working together to make one complete living and changing system. The natural system of a landform consists of these elements:

   A. Geology is the study of earth's history stored in rock. It is the study of the mineral composition and the pressure formation of rock, and the study of three different types of rock: metamorphic, igneous and sedimentary and their structural characteristics.

   B. Soil horizons - the study of the layering and types of soils composing each horizon or layer. Soil horizons comprise the majority of earth above the bedrock layer.

   C. Hydrology - the study of the amount and movement of water on the earth; the study of flooding and average large yearly rainfalls; and the study of drainage patterns on slopes.

   D. Vegetation - the study of the development, stage of succession and association of plants growing in different ecological zones.

   E. Built structures - the documentation of the manmade structures in the landscape (for example: underground wires and pipes, walks, streets and buildings).

   F. Climate - the study of weather changes in a geographical area, such as in temperature, rainfall, snowfall, wind and sun angle.

II. Site Analysis. A site analysis consists of a collection of maps presenting data on the previous natural systems which make up a landform. A site analysis usually consists of the following maps:

   A. Site boundaries
   B. Topological study
   C. Slope study
   D. Soils study
   E. Vegetation study
   F. Architectural study
   G. Hydrological study
   H. Geological study
   I. Climatological study
   J. Wind study
   K. Solar Study

   (Some of the previous studies can be combined onto one map, but most need to be mapped individually. An explanation of each of the studies will follow.)

III. Site Boundaries. Site boundaries determine the size and ownership of a parcel of land and are determined by specific survey data.

   A. Survey data consists of reference points and line bearings.

      1) Reference points. From a reference point on a site map a surveyor can determine all the remaining reference points by using bearings.

      2) The bearing gives the surveyor the degree of the angle of a line directly off a line either direct north or south. For example, "North 90 degrees East 51'" means that a surveyor would point the equipment due north and then swing it 90 degrees east and the next point would be 51' in this direction. (For illustration see Figure 3.1)

   B. Due to the need for technical equipment and the problems which might arise if the survey is not entirely correct, a planner should use a professional surveyor.

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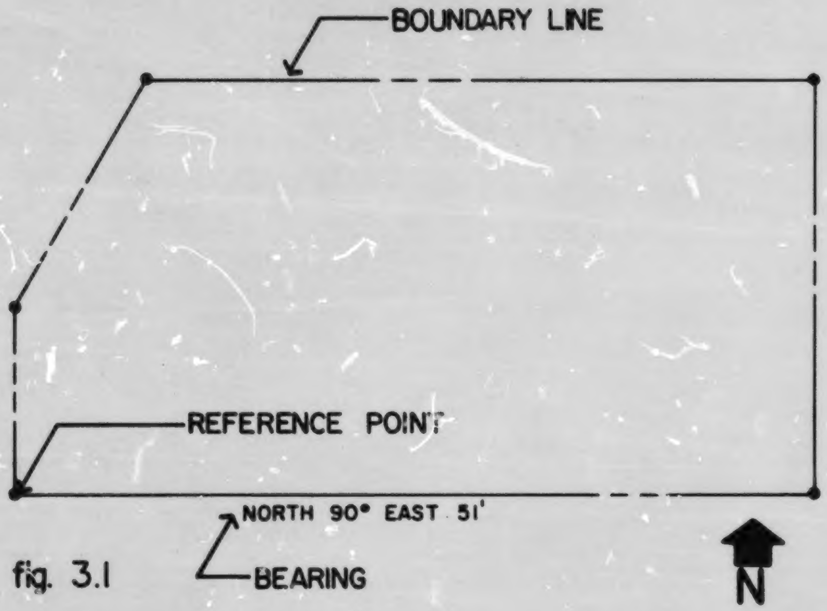

BOUNDARY LINE
REFERENCE POINT
NORTH 90° EAST 51'
BEARING
N

fig. 3.1

IV. Topological Study Maps and Slope Maps.

A. Contours- a line on which all points on that line exist at the same elevation. Every contour line closes on itself, either within or beyond the limits of the map. (See Figure 4.1)

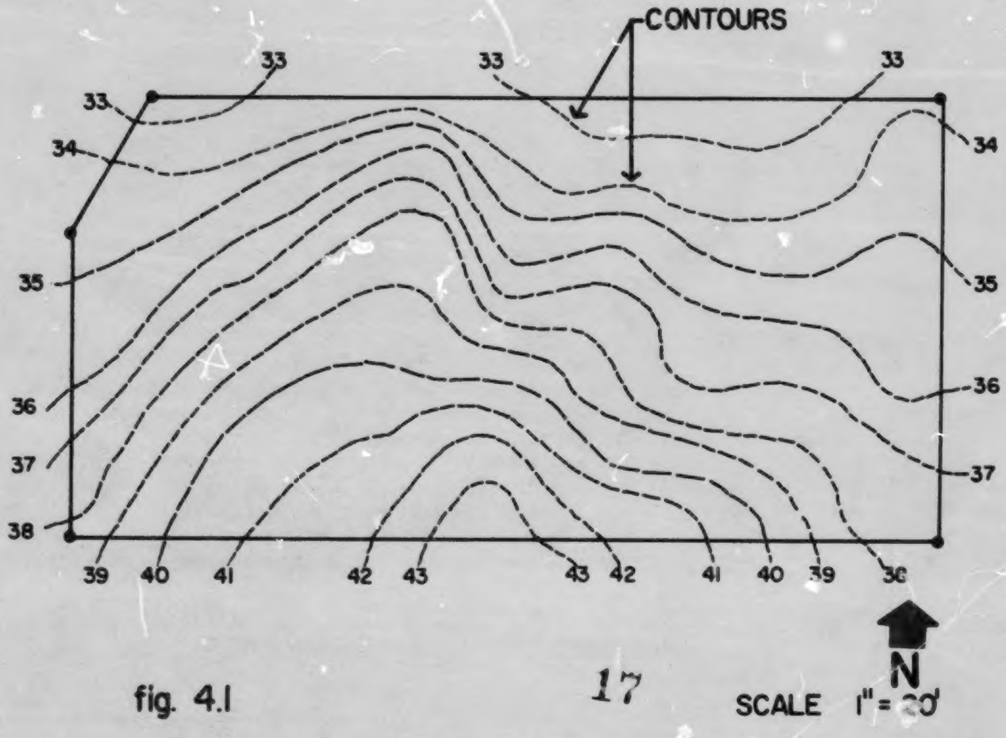

CONTOURS
33
33
33
33
34
34
35
35
36
36
37
37
38
39
40
41
42
43
43
42
41
40
39
38
N
SCALE 1" = 20'

fig. 4.1

1) A set of contours which close on themselves in a certain area of a map can depict either a low point (L.P.) (See Figure 4.2) or a high point (H.P.) (See Figure 4.3).

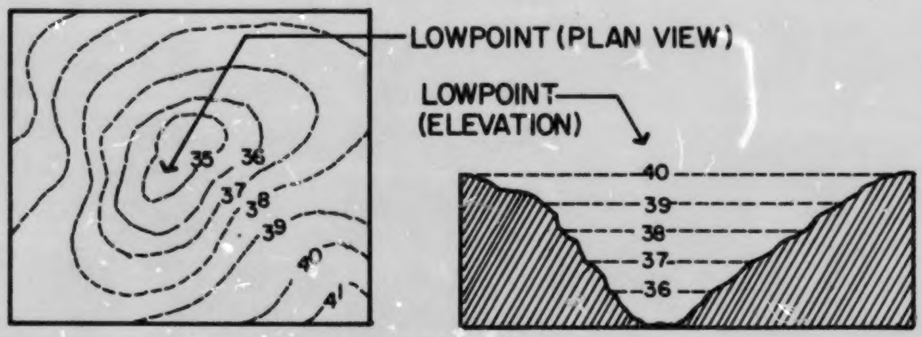

LOWPOINT (PLAN VIEW)
LOWPOINT (ELEVATION)
35
36
37
38
39
40
41
40
39
38
37
36

fig. 4.2

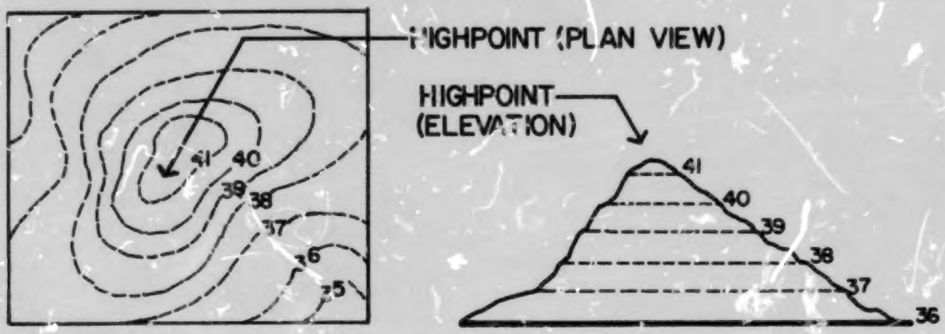

HIGHPOINT (PLAN VIEW)
HIGHPOINT (ELEVATION)
41
40
39
38
37
36
35
41
40
39
38
37
36

fig. 4.3

2) One can determine whether it is a low point or a high point by looking at the procession of numbers on the contours. If the numbers get higher towards the center it is a high point; and if the numbers get lower towards the center it is a low point.

3) Contours never cross except in the instance of an overhang. (See Figure 4.4)

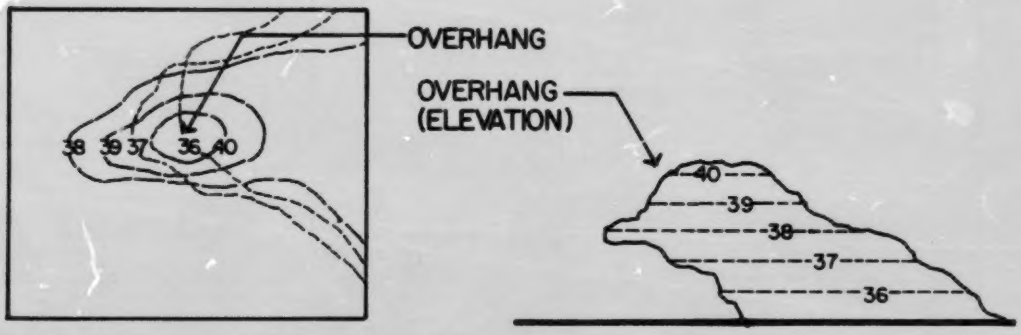

OVERHANG
OVERHANG (ELEVATION)
38
39
37
36
40
40
39
38
37
36

fig. 4.4

4) Contour intervals. Measure the vertical distance between the contours. The larger the contour interval the fewer contours which will appear on the topography map. The smaller the contour interval the more contours that will occur on the map. Larger contour intervals are frequently used on maps of sites with large acreage. (See Figure 4.5)

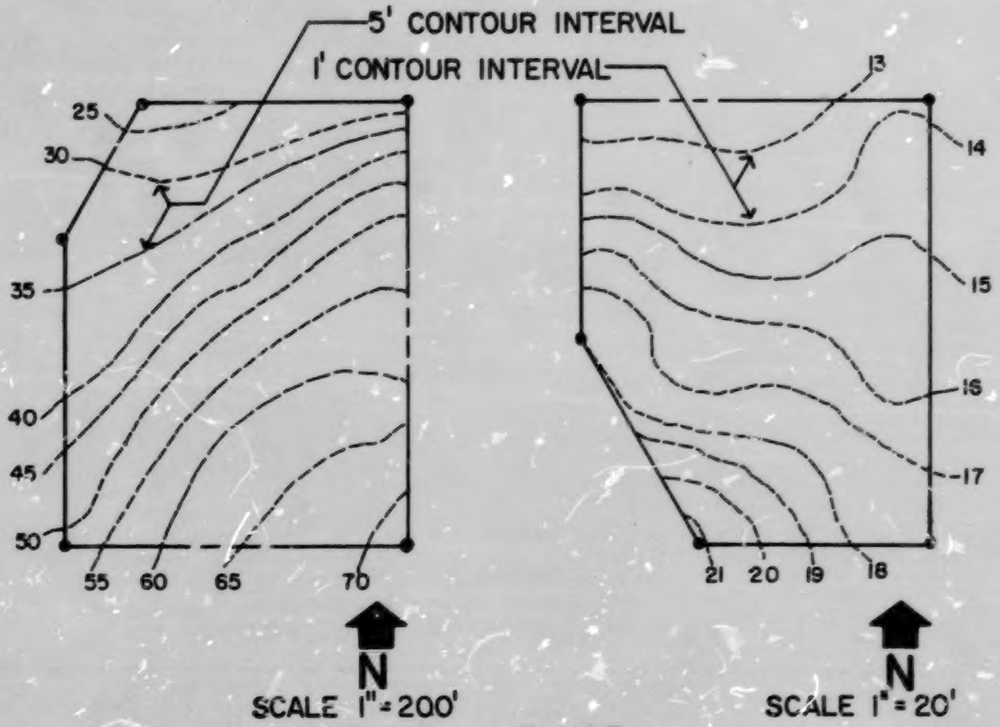

5' CONTOUR INTERVAL
1' CONTOUR INTERVAL
25
30
35
40
45
50
55
60
65
70
N
SCALE 1"=200'
13
14
15
16
17
21
20
19
18
N
SCALE 1"=20'

fig. 4.5

B. Topography. The word topography describes a set of contours which determine the surface features or relief of a site. By learning to read a topographical map you will learn how to recognize such land features as low points (See Figure 4.2), high points (See Figure 4.5), ridges, creek and river beds (See Figure 4.6).

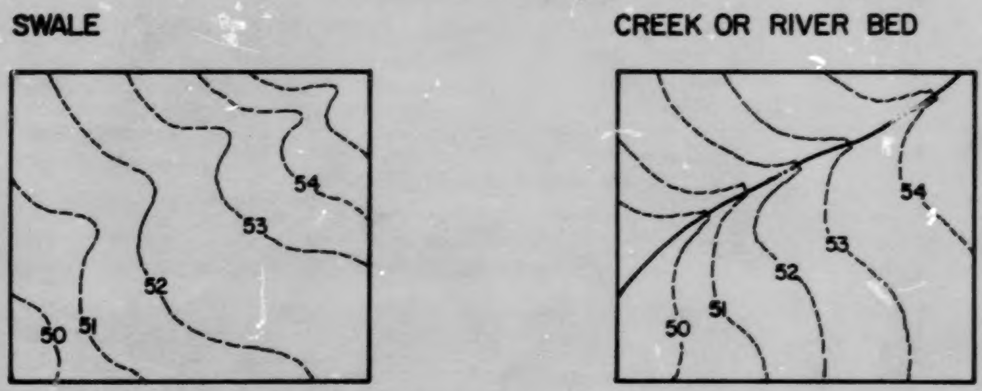

SWALE
54
53
52
50
51
CREEK OR RIVER BED
54
53
52
51
50

fig. 4.6

1) The study of topography helps in determining the direction and effect of wind and water on a site.

2) One of the best methods for studying topography is through the use of a slope map.

C. A topographical map contains complete topographic information (of a site) such as all contours at their correct interval and elevation points showing high and low elevations and building and road elevations.

D. Slopes, A slope is determined by vertical rise divided by the horizontal run of a contour interval. The number arrived at here is then changed to a percentage by moving the decimal place two figures to the right. Thus we arrive at this equation:

$$\frac{\text{Rise}}{\text{Run}} = \text{Percentage of Slope}$$

1) For example, think of a strip of land a hundred feet long. If the strip is part of a hill and there is 10 foot of rise in this 100 feet, then this land has a 10% slope. This means for every 100 feet of run there is 10 feet of rise or for ever 10 feet of run there is 1 foot of rise.

$$\frac{\text{Rise}}{\text{Run}} = \frac{10}{100} = \frac{1}{10} = .1 \text{ or } 10\%$$

2) Example: Where "a" and "b" are consecutive contours, the difference between "a" and "b", "b" being the highest elevation, equals the rise factor in the above equation. The horizontal factor can be determined by actually measuring with a scale between the two contours. Thus you will now have derived factors to plug into your equation.

a = 31
b = 32
Run = 10

$$\frac{32-31}{10} = \frac{1}{10} = .1 \text{ or } 10\%$$

E. Slope maps. A slope map is the two dimensional mapping of three basic slopes: good or gradual slopes, workable slopes, and steep slopes. This mapping system helps the planner to determine good building areas, difficult grading areas and flood plains.

How to make a slope map

1) You must start with a complete topographic map.
2) You must then determine the location on this map of the three slopes or gradients most worked with:
   - 0-8% a good or gradual slope
   - 8.1-15% a workable slope
   - 15.1% and over requires major grading
3) A general rule to remember is that as contours get closer together, the slope becomes steeper and the percentage of slope becomes larger.
4) In order for a planner to determine what an 8% slope would look like on a particular topographic map, he/she must first determine the horizontal distance that an 8% slope would occupy between contours. Find the contour interval (CI) of your map (which equals the rise factor). The CI for this map will be 1 foot.

$$\frac{100 \times \text{CI}}{\text{Percentage of Slope}} = \text{Horizontal Distance Between Contours}$$

$$\frac{100 \times 1'}{8\%} = X \qquad \frac{100}{.08} = 12.5'$$

Therefore, everywhere the measured horizontal distance between contours equals 12.5', there is an 8% slope.

5) Now solve the above equation for 15% and then using a scale equal to the one used on your topographic map make a guide rule of cardboard or some other sturdy material. (See Figure 4.7)

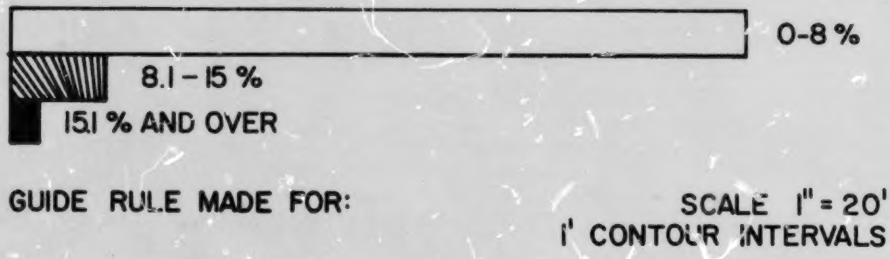
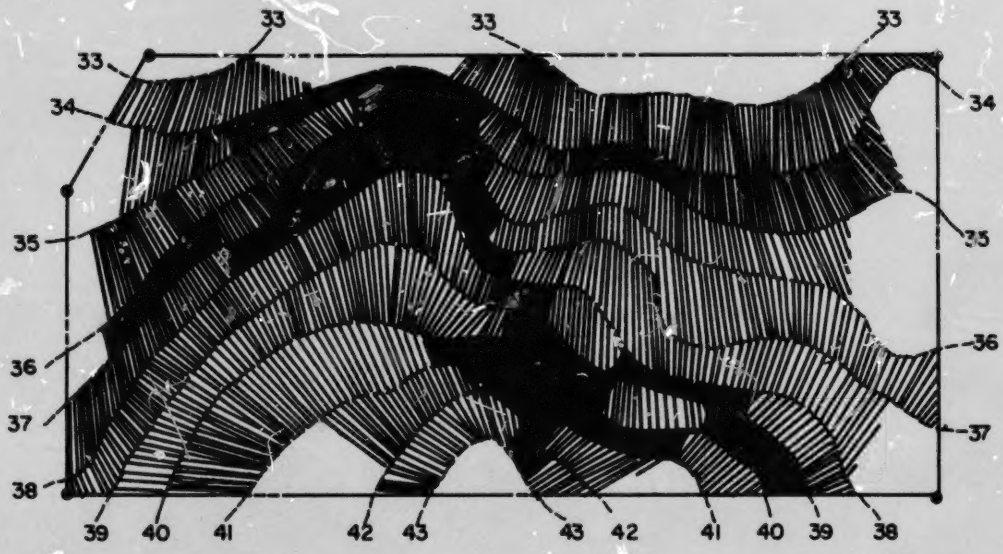

0-8 %
8.1 - 15 %
15.1 % AND OVER
GUIDE RULE MADE FOR:
SCALE 1" = 20'
1' CONTOUR INTERVALS

fig. 4.7

6) Use your marked guide to run along the contours in a perpendicular motion. Mark off the areas belonging to each set of slope measurements. (See Figure 4.8)


33
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38

N

☐ 0-8% EXCELLENT SLOPE

▨ 8.1-15% WORKABLE SLOPE

■ 15.1% AND OVER REQUIRES EXCESSIVE GRADING

SCALE 1" = 20'

fig. 4.8

V. Soils. Soils make up the loose surface material of the earth in which plants grow. Soils are comprised of decomposing organic and inorganic materials and contain nitrogen and oxygen gases, water, minerals and living organisms. Soils occur in vertical layers or horizons above the bedrock layer. Each horizon will have some difference in its mineral and particle composition.

A. Soils are classified by their particle size.
   1) Sand has a very large particle size, is highly aerated but has low water holding capability.
   2) Silt has a medium particle size, very low aeration and a medium water holding ability.
   3) Clay has a small particle size, low aeration but a very high water holding ability.

B. The aeration of a soil is equal to the volume of air contained in that soil.

C. Hydration of a soil refers to the volume of water retained in that soil.

D. The organic matter contained in the soil provides food for micro-organisms which in turn are necessary for nitrogen fixation.

E. The minerals in the soil are broken down and utilized by plants for growth.

F. Plants depend on nitrogen for the production of food, on phosphorus to stimulate root growth, flowering and fruiting; and on potash as a catalyst for nitogen fixation.

G. Soil surveys
   1) A soil survey will usually give the planner all the information he/she could need on the soils in his/her areas. A soil survey is usually done by county and can be found through the U.S. Conservation Service in your county. You will have to locate your site on the survey and record the corresponding soils onto your soils map.
   2) Check the abbreviation of each soil and match it to the corresponding name in the survey. Under the name you will find such information as the fertility, building capabilities and composition.

H. Soil maps
   1) A soils map is composed of your site overlaid with its corresponding soils.
   2) This map will enable the planner to easily locate and develop the soils to their best usage.

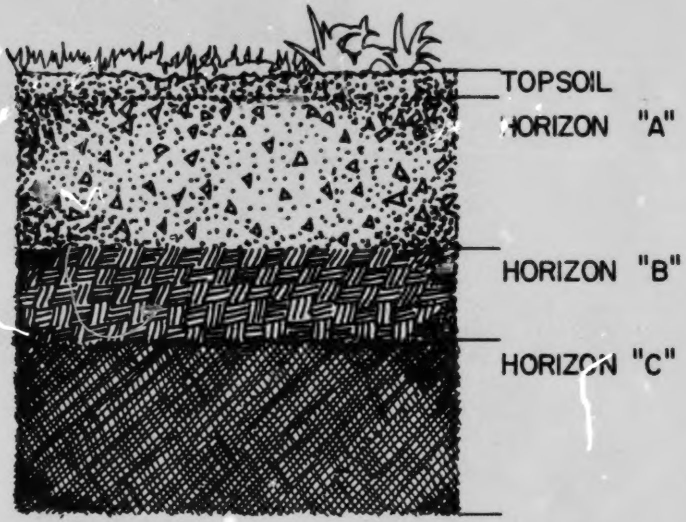


fig. 5.1

NOTE: In the earth, soils occur in layers called horizons. Each horizon is usually composed of some of the same organic matter and minerals as the horizons surrounding it, but will differ in age and formation. (see fig. 5.1)

VI. Vegetation

A. The study of vegetation on a site takes an accounting of all types of plants appearing on the site. Large trees, small trees, shrubs, grasses, vines and herbs should be listed in this study. The amount, size and type of vegetation will affect the movement and changes wind and water have on the site.

1) Evergreens are plants which maintain their foliage all year around.

2) Deciduous plants lose their foliage during seasonal changes such as a lower temperature and a shorter daylight period.

3) Specifications affecting the usage of plants:
   (a) Size
      1. Height (See Figure 6.1)
      2. Dripline, or the circumference of canopy (See Figure 6.1)
   (b) Density
      1. Leaf size
      2. Surface texture
      3. Branching texture
   (c) Root structure

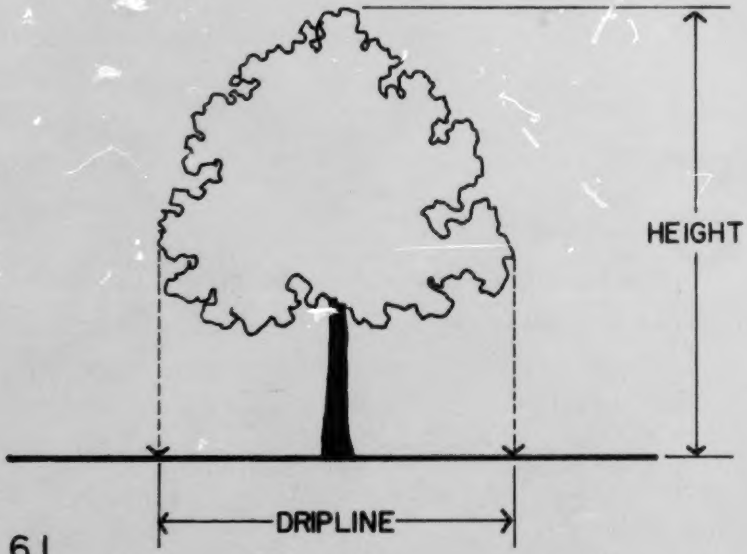


fig. 6.1

B. Vegetation maps

1) A vegetation map lists and locates all the major plants and trees on the site. It either gives the common or botanical name on the location of the plant, and then lists both names in the key along with other information about the particular specimen.

2) A vegetation map enables the planner to save important trees or plants on the site for the beneficial use of the entire plan.

VII. Architectural Study

An architectural study provides information and location of all built structures on the site. Built structures include buildings, walks, streets, wiring and underground pipe.

A. Architectural maps should include such information as the orientation of buildings and the location of windows in these buildings.

B. Orientation. The orientation of a building gives the location of the face of the building and indicates the route the sun will take in relationship to the building. It will help plot the direction seasonal winds will take in regard to the building.

C. Usage. An architectural study should include the usage or function of the buildings, walks, streets and underground utilities. This information will enable the planner to incorporate the needs of these functions into the design.

D. Energy efficiency. In order to determine the energy efficiency of a building, one must determine the insulation factor of building materials, the type of energy used in the building, and if the building or buildings utilize any of the surrounding natural systems.

VIII. Hydrological Study - The study of the physical movement of water on the site both temporary (due to rainfall) and constant (due to creeks and rivers).

- A. A planner uses a hydrology map to aid in erosion control and in flood control.
  - 1) Erosion is the gradual wearing away and removing of the earth's soil by either wind or water.
  - 2) Controlling flooding is one of the most important aspects of design. By determining areas which are most likely to flood, the planner can refrain from building in these areas. By considering the situation and planning for good drainage in times of large rains, the planner can better control flood waters.
- B. A hydrology map can be calculated in one of two ways: 1. By using a slope map, or 2. By studying a contour map.
  - 1) By using a slope map to determine the flow of rain waters off steep slopes onto low plains, the planner can begin to map areas which might flood. You should also map areas where there is a continuous flow of water. Mark the direction you think the water would move coming off the slope, remembering that in theory water runs perpendicular to the contours and always takes the easiest route.
  - 2) One would use a contour map much like a slope map. Follow steep areas (or areas with close contours) into low plains (or areas where contours are further apart) and map these areas using arrows to give the direction of the water. Also map areas where there is a continuous flow of water.

IX. Geological Study -A study of the rock and minerals lying beneath the soil layer on the site. This study includes information on the building potential of the bedrock layer in the area.

- A. The planner cannot do this study alone, and therefore must rely on U.S. Geological Survey data.
- B. Locate and secure a map of your county from the U.S. Geological Service and pinpoint your site on this map using such landmarks as railroads, highways, creeks and rivers.
- C. In most cases a geological survey is not needed unless the site is very large (200 acres or so) or there will be an extensive building program in the development of the site.

X. Climatological Study- The study of the average snowfall, rainfall and temperatures in the seasonal changes of an area. You will be able to find this material from the local weather service. This material will probably be compiled in a small booklet which will explain weather occurrences in the area.

- A. Snowfall. The information about the average snowfall will help in solar estimations.

B. Rainfall. Knowing the amount of rainfall in an area will enable you to calculate the number of overcast days.

C. It is very important to know the average temperature in each season in order to calculate the use of natural systems and the energy of natural systems. One important factor not mentioned in most weather books is the effect of humidity on the temperature. These differences can be detected throught the use of dry bulb and wet bulb thermometers.

1. A wet bulb thermometer can be made by placing the bulb of the thermometer into cotton gauze and then into a saucer of water. (See Figure 10.1)

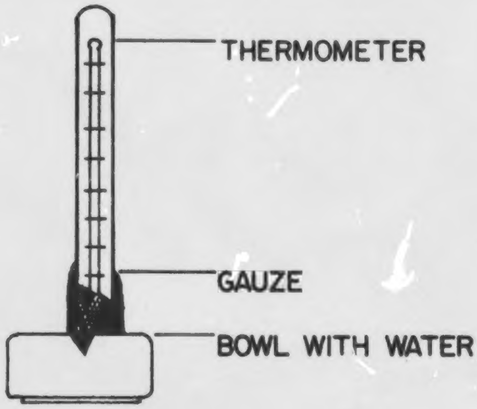


fig. 10.1

2. A dry bulb thermometer is any common thermometer found in a store. The wet bulb/dry bulb relationship is best demonstrated by a theoretical example. When the dry bulb readings of Phoenix, Arizona (dry climate/low humidity) and Savannah, Georgia (wet climate/high humidity) are both 70 degrees Fahrenheit, the wet bulb temperatures can differ by as much as 15 degrees. Phoenix, Arizona might be 60 degrees because moisture from the wet bulb reading evaporates into the air, which causes a cooling effect. Savannah, on the other hand, has such high humidity that there is less air space for moisture to evaporate into; thus, there will be little difference between wet and dry bulb readings. Wet bulb measurements in Phoenix could be 60 degrees, while Savannah might be 68 degrees. (See Figures 10.2 & 10.3)

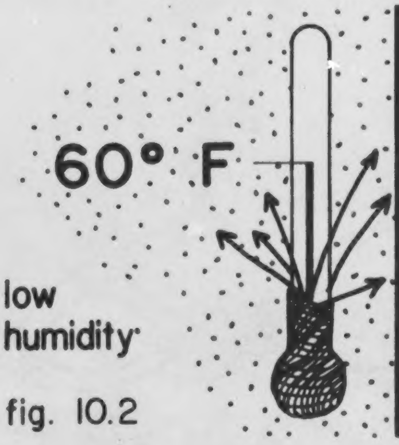


fig. 10.2

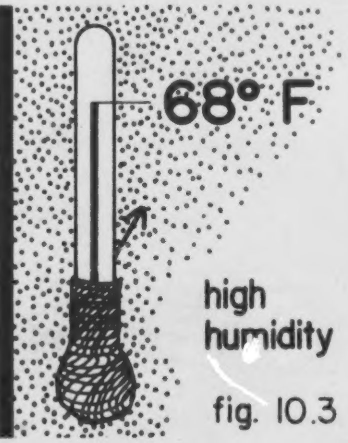


fig. 10.3

3. High humidity is seldom a desired factor in any temperature. In the summer, days are "muggy" because highly saturated air prevents evaporation which is necessary for natural cooling. In the winter, the moisture in the air will cool and fall to the ground as frost.

XI. Wind Study - The study of the seasonal changes in direction and intensity in the wind. Charts of wind direction and intensity can be obtained for particular areas from the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina.

A. Direction. In North Carolina, the winds are generally from the southwest, but during August, September and October, the wind direction reverses and comes from the northeast.

B. Wind Principles. Two properties of air, pressure and velocity, will change inversely when the current encounters an obstacle.

1. When velocity increases, pressure drops.
2. When velocity decreases, pressure will increase. (See Figure 11.1)

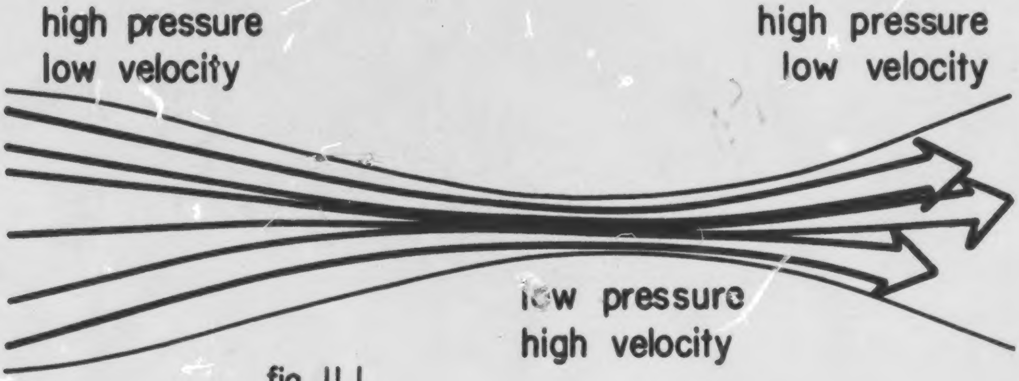


fig. 11.1

C. Sometimes referred to as the Venturi Effect, this channeling of wind to increase air speed is often used to enhance the performance of wind generators.

1. Winds always will follow the course of least resistance.
2. Wind currents can be classified as either laminar or turbulent. (See Figure 11.2)

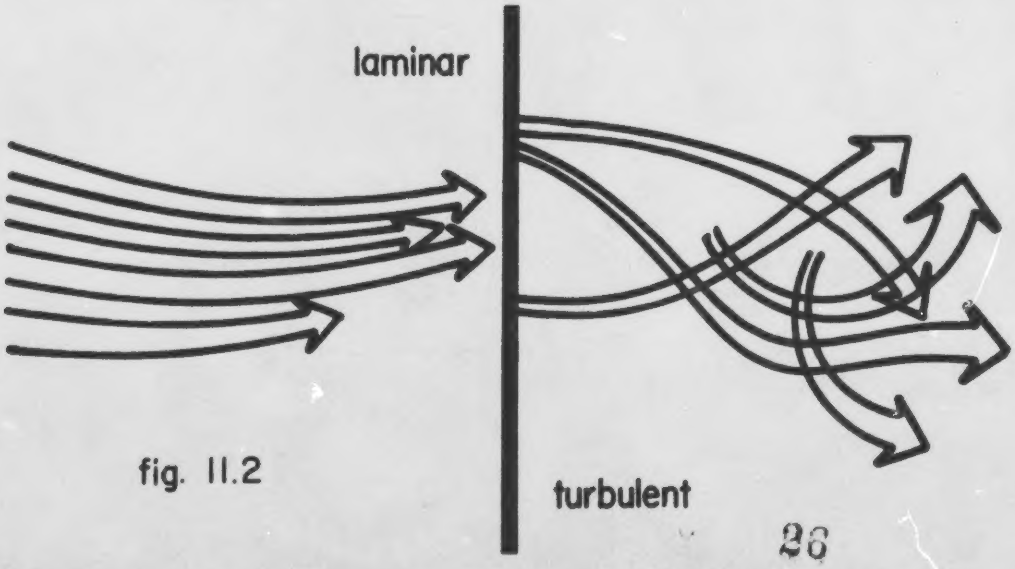


fig. 11.2

3. Ways in which wind can be controlled:
   a. deflected (See Figures 11.3)
   b. filtered (See Figure 11.4)
   c. blocked (See Figure 11.5)

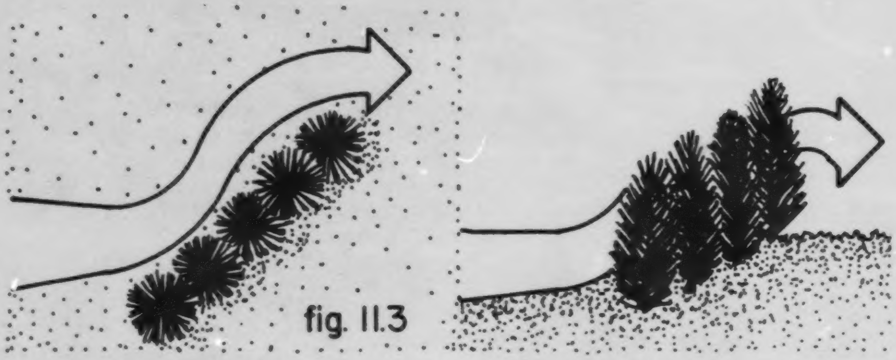


fig. 11.3

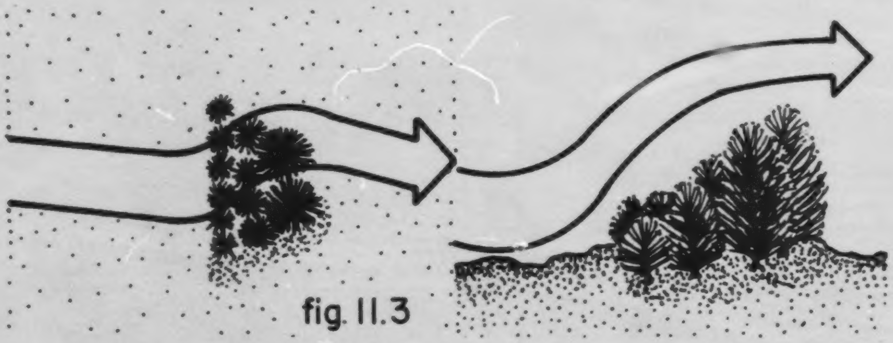


fig. 11.3

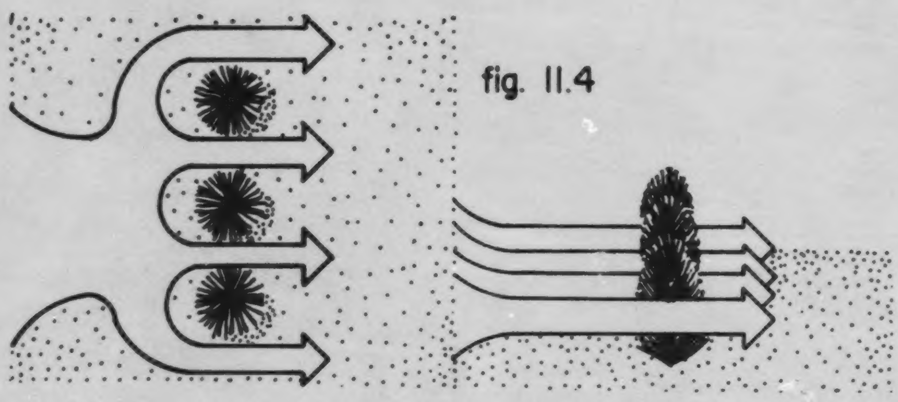


fig. 11.4

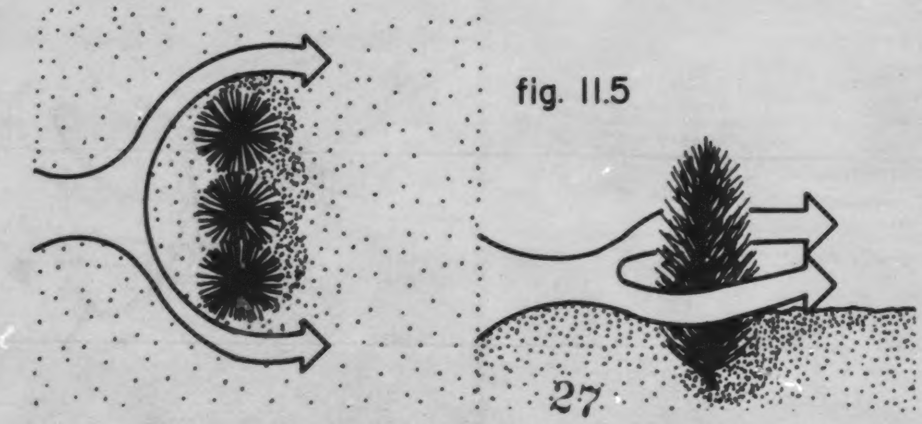
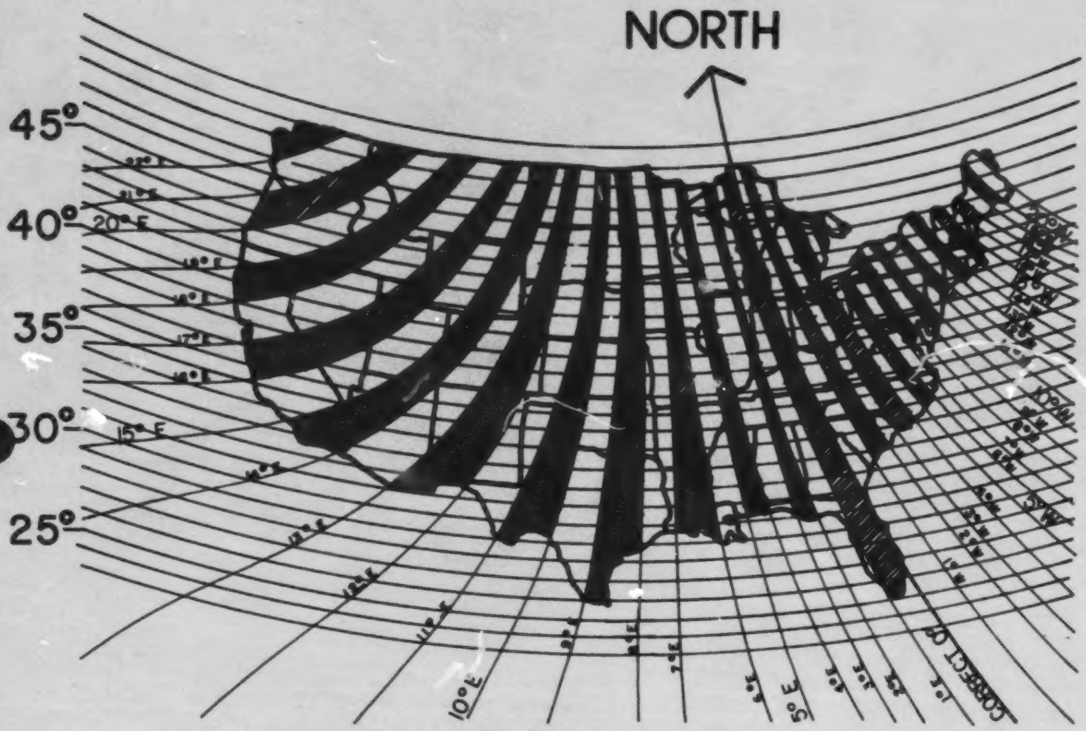


fig. 11.5

XII. Sun Study

The sun's path, though complex, is predictable for any geographic area. Knowledge of the sun's movement across the sky will enable you to manipulate landforms, vegetation and the built environment in order to meet the needs and requirements of a particular region. Knowing the degree to which the site is affected by the sun throughout the year will allow you, the designer, to create a successful system, without the need of guess work.

A. Orientation is critical in order to accurately plot the sun's path. There are two different north directions. Most maps, unless otherwise specified, are oriented to magnetic north. True north is considered correct when charting the actual solar path in reference to a particular site. True north can be derived from magnetic north by using the adjustment figure which corresponds to the geographic location of the site. (See Figure 12.01)



1 LINE = 1° CORRECTION

fig. 12.01

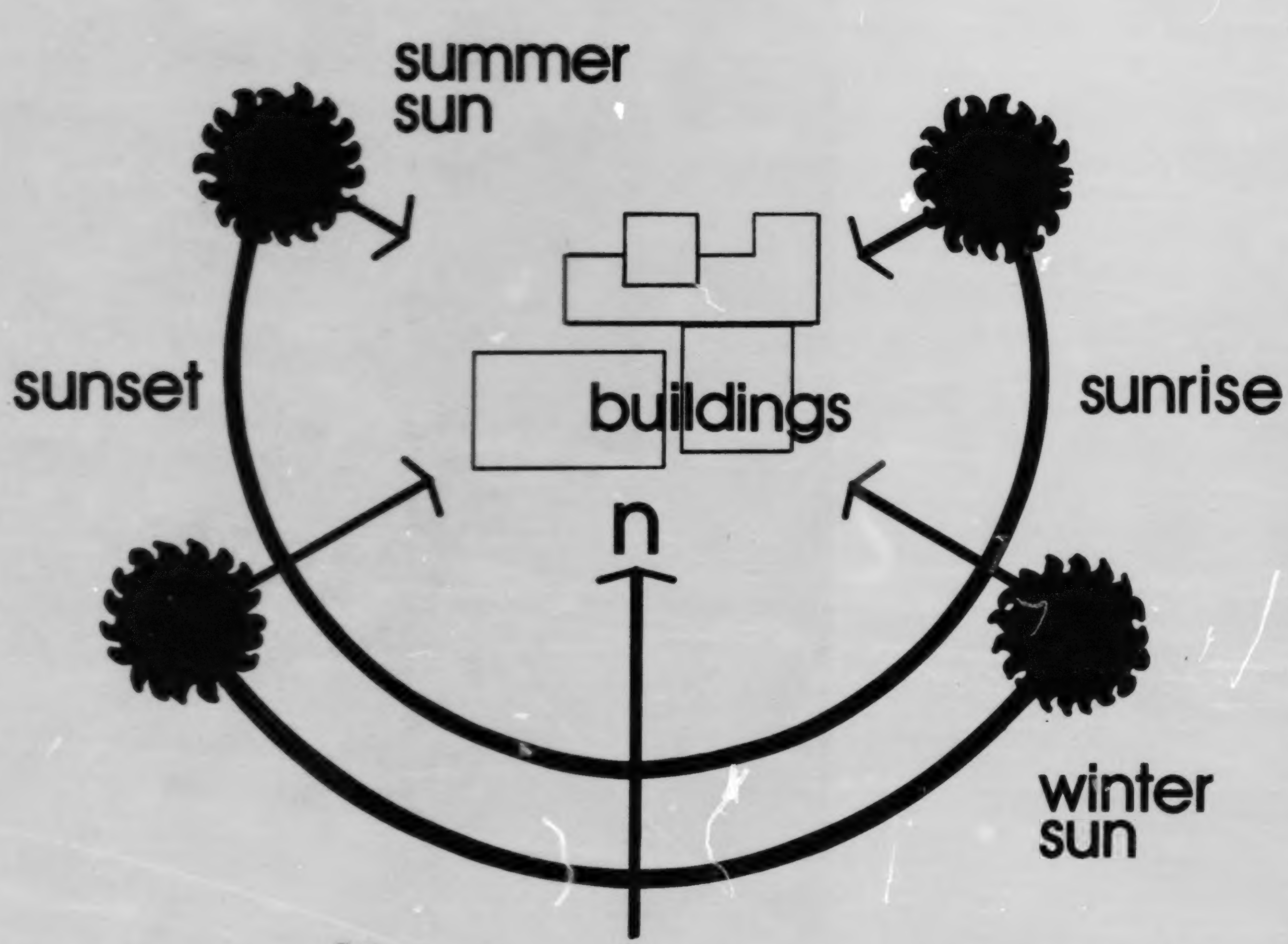
In fig. 12.01 the line labeled correct 0 is the only region in which true north and magnetic north are one in the same. All other areas will need to add an additional arrow designated "true north".

A base map (magnetic north orientation) can be corrected to true north by:

1. Finding the site location on the U.S. map.
2. Finding the adjustment figure which corresponds to site location.
3. Adding this figure to the existing north orientation angle and adding a new true north arrow. (Use true north for solar; use magnetic north arrow for other site work.)

B. The latitude of a site is another determinate when plotting the sun's movement. Latitude determines the solar angle(altitude) as well as the solar path(azmuith). See fig. 12.02 & 12.03.

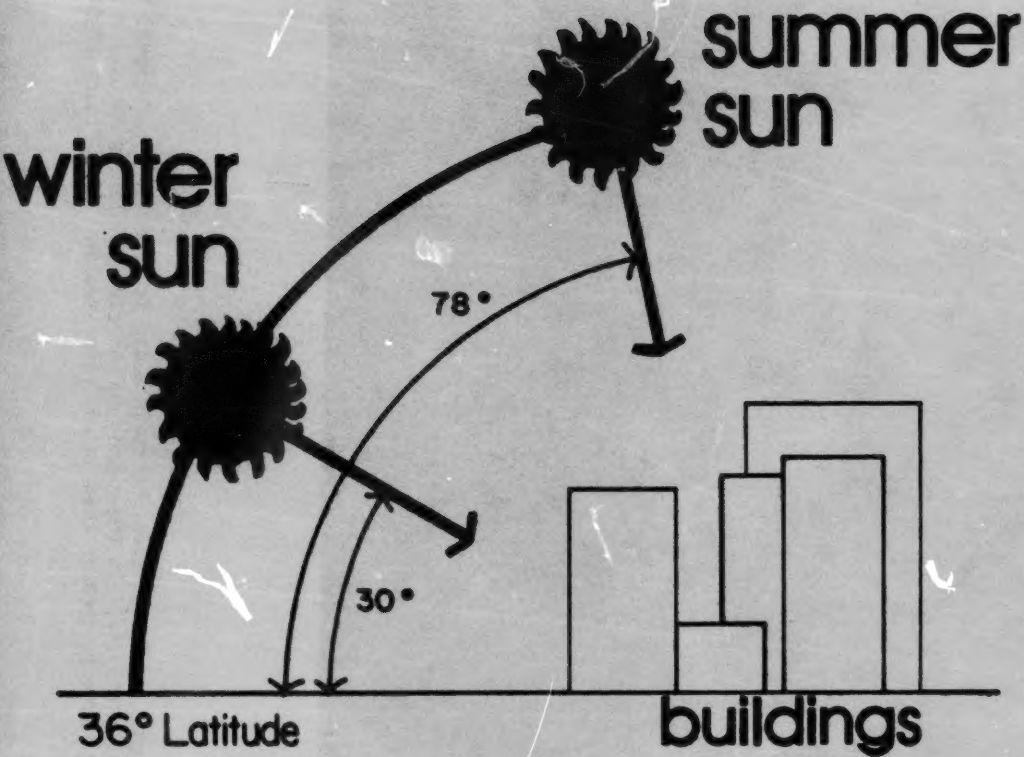
C. Summer days are longer and winter days shorter because of variations in the sun's path throughout the seasons. (See Figure 12.02)


summer sun
sunset
buildings
n
sunrise
winter sun

sun path 36° Latitude fig. 12.02

21

D. The sun always rises to its greatest height in the sky during the summer months of June, July and August. In the months of November, December and January the sun is at its lowest point in the sky. (See Figure 12.03)


summer
sun
winter
sun
78°
30°
36° Latitude
buildings

sun angle

fig. 12.03

E. The total number of solar hours in a day is directly proportional to the sun's angle in the sky. In the summer months (June, July and August) the total of solar hours is greater than in any other season. (See Figure 12.04)

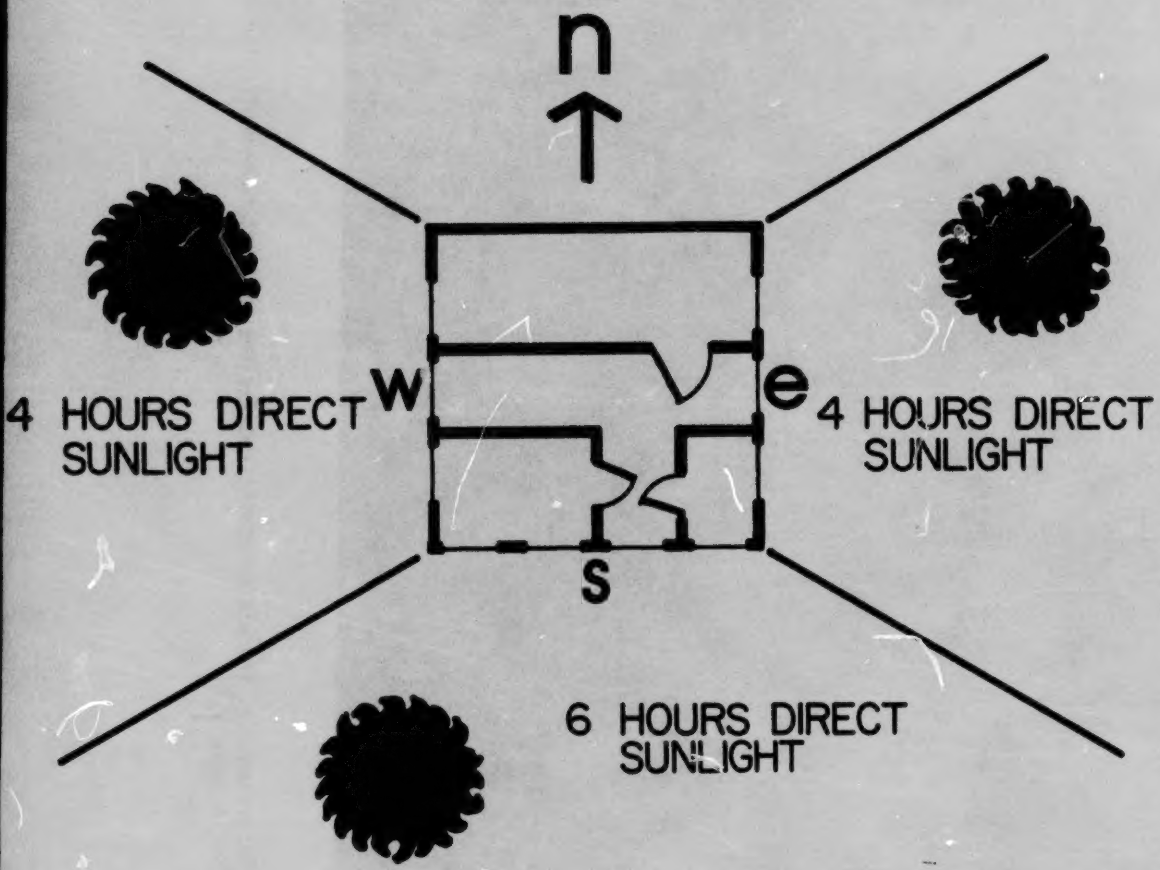

n
w
e
s
4 HOURS DIRECT SUNLIGHT
4 HOURS DIRECT SUNLIGHT
6 HOURS DIRECT SUNLIGHT

fig. 12.04

summer sun

Proportionally, the winter months receive the smallest number of solar hours. (See Figure 12.05)

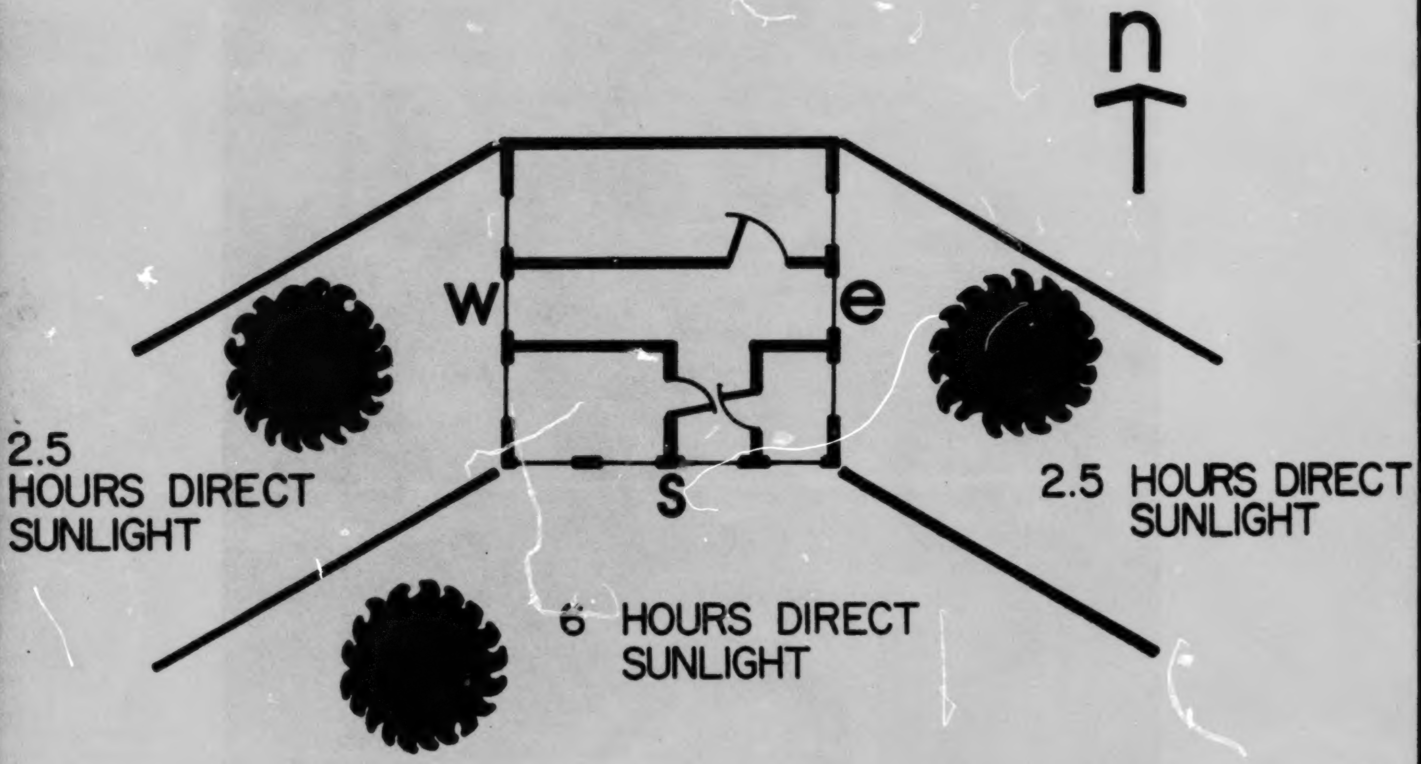

n
w
e
s
2.5 HOURS DIRECT SUNLIGHT
2.5 HOURS DIRECT SUNLIGHT
6 HOURS DIRECT SUNLIGHT

fig. 12.05

winter sun

F. Solar radiation is filtered by earth's atmosphere before it reaches the planet's surface. The remaining light, which we call sunlight, is comprised of ultraviolet radiation, visible light and infra-red light. Ultra-violet light causes sunburn as well as discoloration and fading of materials. Visible light contains all the colors of the spectrum. Infra-red provides the major source of heat found in sunlight. (See Figure 12.06)

solar radiation composition

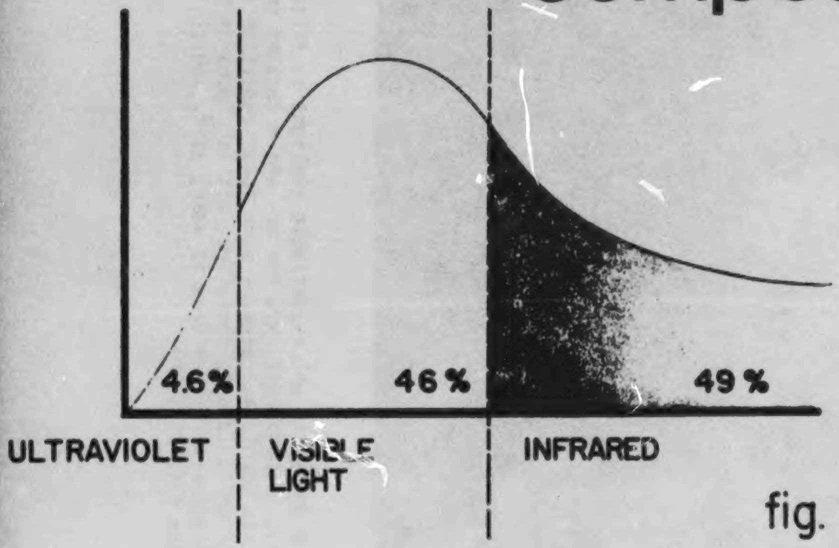
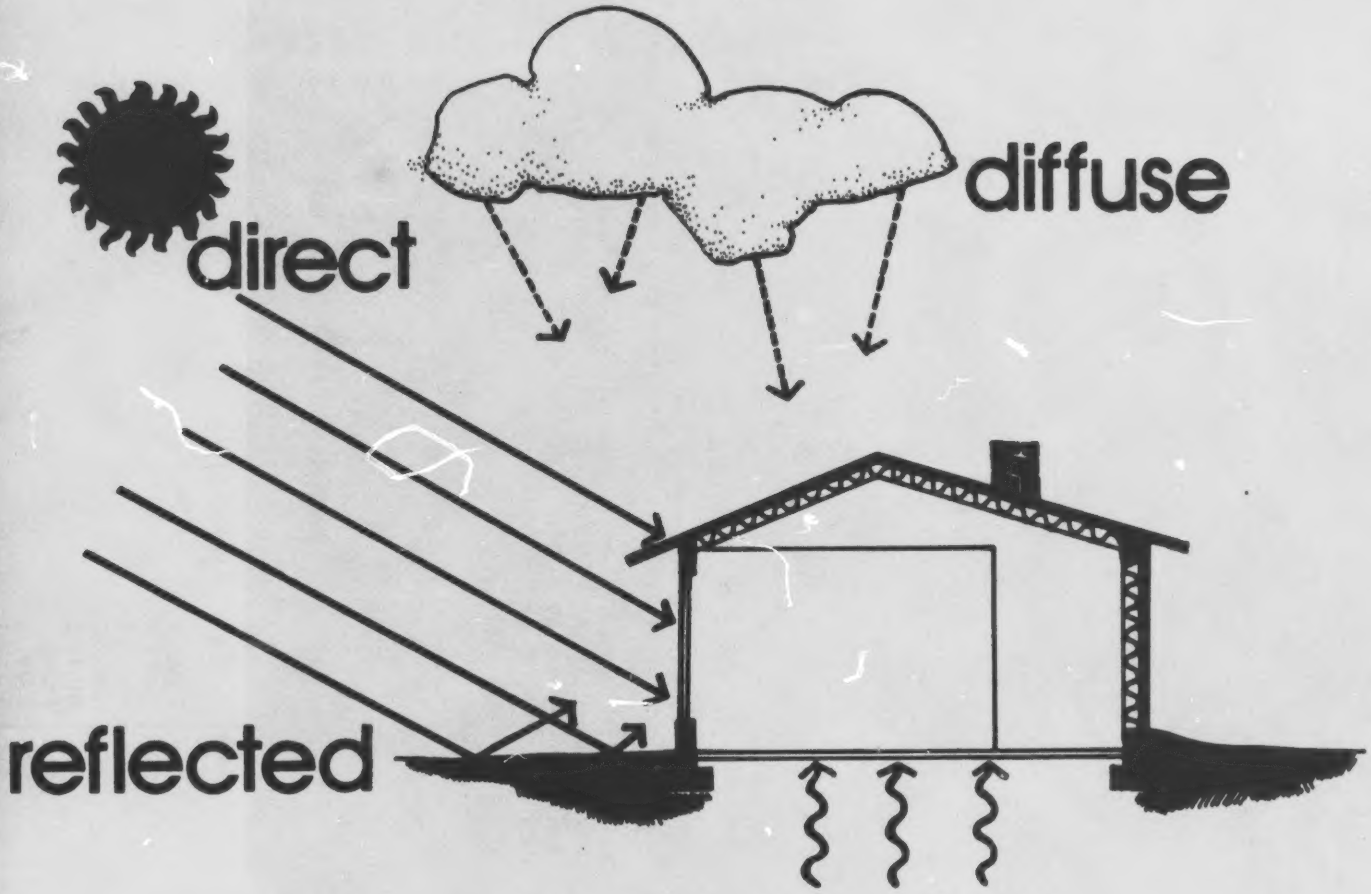


fig. 12.06

G. The degree to which available sunlight is filtered depends on the clearness of the day. Albuquerque, New Mexico, while located on the same latitude as Raleigh, North Carolina, receives more solar radiation than Raleigh because the days are not as humid and, therefore, not as cloudy in New Mexico. The degree of cloudiness for any area is noted as $\overline{K}_t$, which is called the cloudiness index. (See Figure 12.07)


diffuse
direct
reflected

types of radiation fig. 12.07

The sum of all forms of radiation falling on a given surface is defined as the Total Solar Heat Gain, and is expressed in square feet. There are two variables affecting Total Solar Heat Gain.

Month
Surface Orientation

Knowing the effect which each of these variables have, alone and in combination, will allow you to make use of passive energy principles for heating and cooling as well.

Using Greensboro, North Carolina, as an example:
Greensboro, NC, Latitude 36° 05' N.; Elevation 891 ft.:

Month	$\bar{H}$	$\bar{K}_t$	Days
Jan	743.9	.469	31
Feb	1031.7	.499	29
Mar	1323.2	.499	31
Apr	1755.3	.543	30
May	1988.5	.554	31
Jun	2111.4	.563	30
Jul	2033.9	.552	31
Aug	1810.3	.538	31
Sep	1517.3	.527	30
Oct	1202.6	.531	31
Nov	908.1	.501	30
Dec	690.8	.479	31

taken from SOLAR RADIATION DATA FOR HORIZONTAL SURFACES. PAGES 59-64.

This information was taken from the tables at the back of this section which list the average daily solar radiation ($\bar{H}$) for each month. In addition, the tables list the cloudiness index for each month. A large $\bar{K}_t$ (cloudiness index) value indicates sunny/clear days. A small $\bar{K}_t$ value represents cloudy overcast weather.

The monthly values given for $\bar{H}$ (monthly average daily total radiation on a horizontal surface), have already taken the cloudiness index into account.

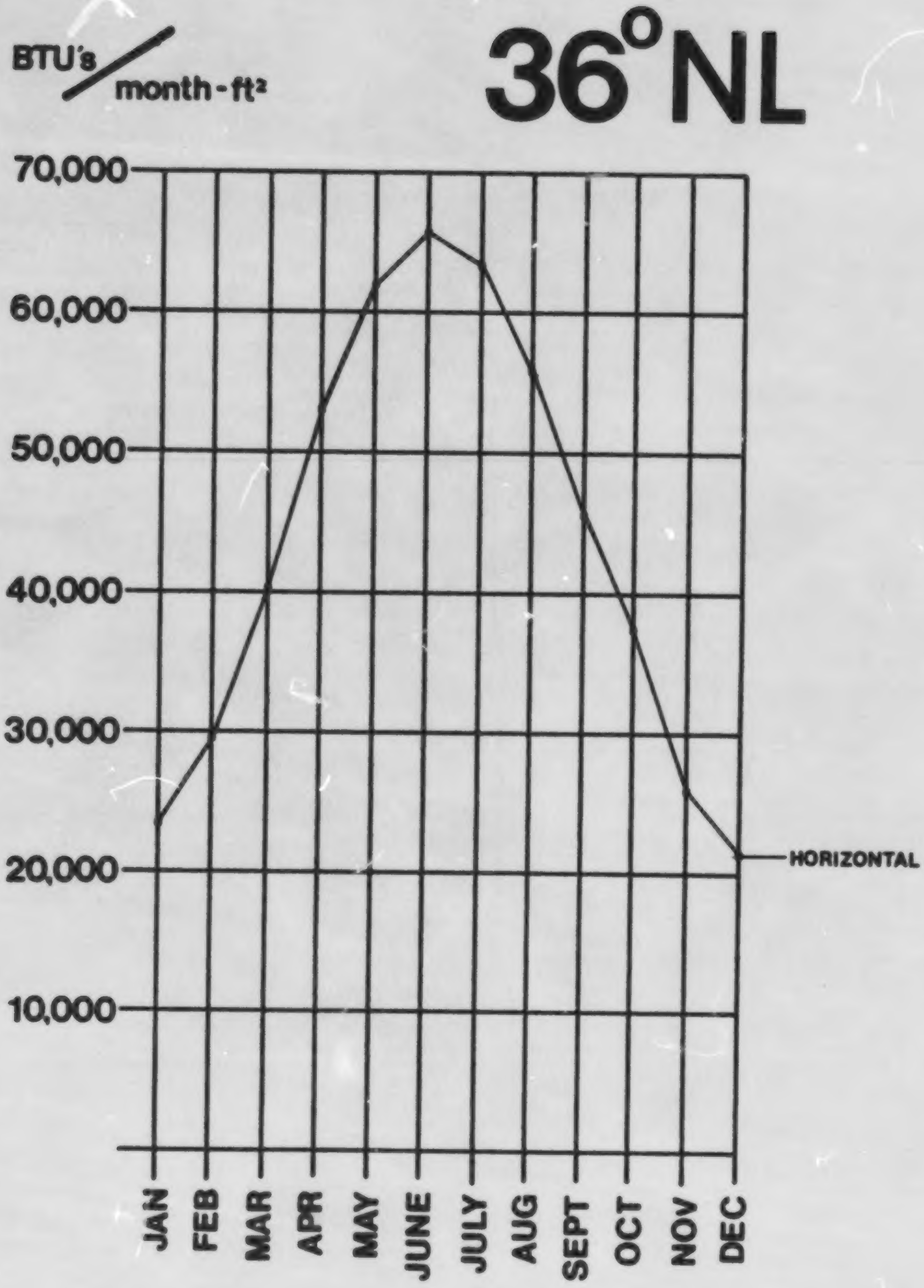
To find the total amount of radiation falling on a horizontal surface for an entire month, simply multiply $\bar{H}$ (monthly average daily total radiation on a horizontal surface) by the number of days in that month. For instance, on an average day in January 743.9 BTUs /ft^2 fall on a horizontal surface.

January = 31 days
($\bar{H}$) X (number of days in month) = $\bar{H}_t$ (monthly total)
(743.9) X (31) = 23060.9 BTUs/ft^2

Completing the table will give the total solar radiation falling on a horizontal surface for each month.

Month	$\bar{H}_t$
Jan	23060.9
Feb	29919.3
Mar	41019.2
Apr	52659.0
May	61643.5
Jun	63342.0
Jul	63050.9
Aug	56119.3
Sep	45519.0
Oct	37280.6
Nov	27243.0
Dec	21414.8

0° tilt



This graph shows the total solar radiation per square foot, falling on a horizontal surface, for each month of an average year.

H. The calculations convert $\bar{K}_t$ factors to $\bar{\bar{R}}$ factors (average daily radiation on a given tilted surface). This has been done for you for various latitudes and tilts in the SOLAR RADIATION DATA FOR INCLINED SURFACES section (pp.55-70). Having found the $\bar{R}$ factor for a desired latitude and tilted surface, one can use the following formula to calculate the total solar radiation falling on a tilted surface for a given month.

$$(\bar{H} \times \bar{R}) \times \text{(days of month)} = \text{BTU/ft}^2$$

Using: Latitude 36° 5'N, Greensboro, NC. (Use Latitude chart for 35°)
Vertical Tilt, 90°

The values of $\bar{K}_t$ for each month when converted to $\bar{R}$ ($\bar{R}$= vertical tilt) are:

Month	$\bar{R}$	$\bar{H}$*	$\bar{K}_t$	Days
Jan	1.35	743.9	.469	31
Feb	1.15	1031.7	.499	29
Mar	0.8	1323.2	.499	31
Apr	.55	1755.3	.543	30
May	0.4	1988.5	.554	31
Jun	.32	2111.4	.563	30
Jul	.36	2033.9	.552	31
Aug	.48	1810.3	.538	31
Sep	.68	1517.3	.527	30
Oct	1.03	1202.6	.531	31
Nov	1.28	908.1	.501	30
Dec	1.48	690.8	.479	31

taken from SOLAR RADIATION DATA FOR INCLINED SURFACES. PAGES 65-82.

* The values for $\bar{H}$ remain the same.

To find the total solar radiation falling on a vertical surface the equation is:

$$(\bar{H} \times \bar{R}) \times \text{(days of month)} = \text{BTU/ft}^2$$

Example: January

$$(\bar{H} \times \bar{R}) \times \text{(days of month)} = \text{BTU/ft}^2$$
$$(743.9 \times 1.35) \times (31) = \text{BTU/ft}^2$$
$$1004.2 \times 31 = \text{BTU/ft}^2$$
$$31132.2 = \text{BTU/ft}^2$$

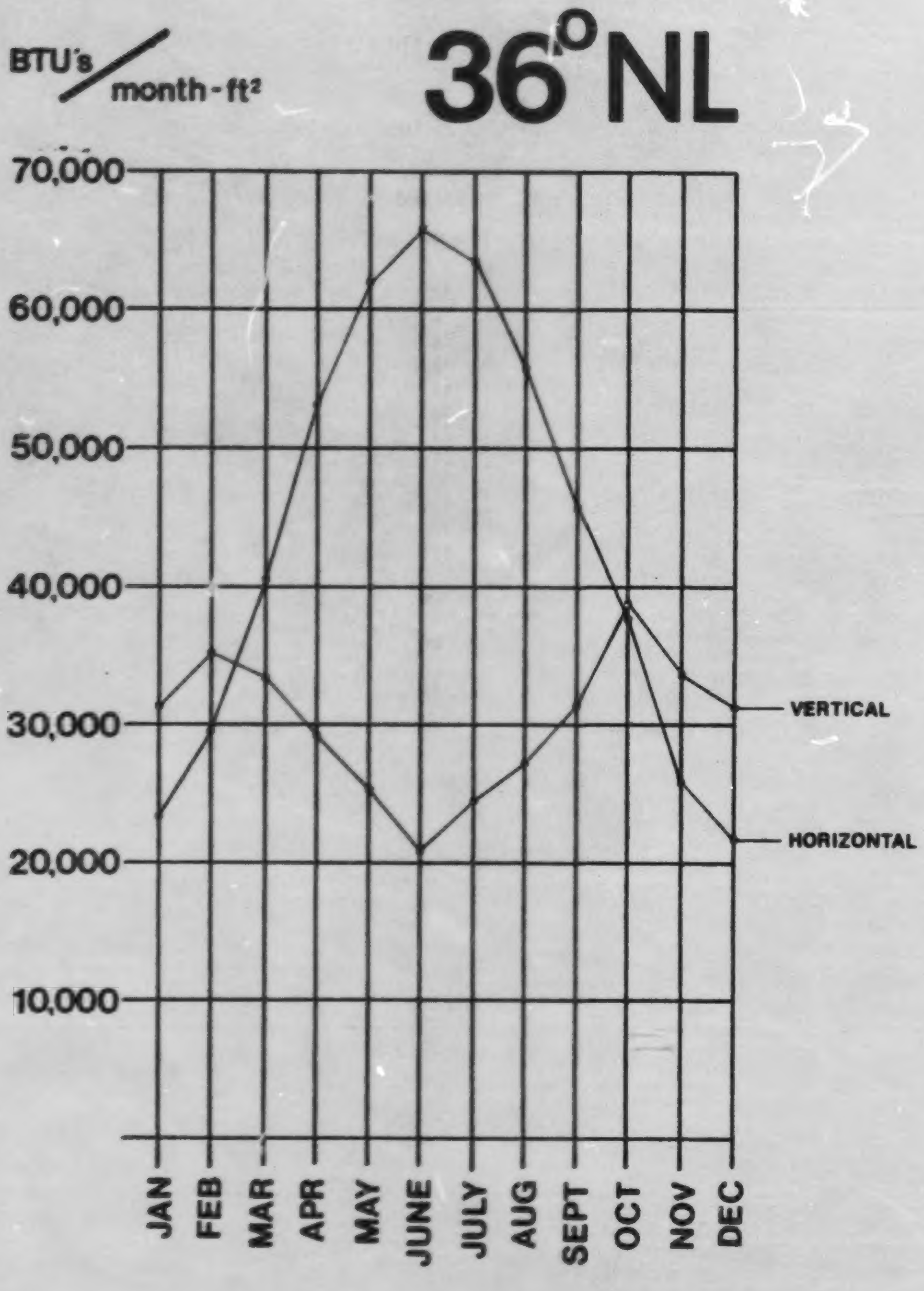
This figure represents the total solar energy falling on a vertical surface for the month of January (in Greensboro, North Carolina).

Completing the table for these values gives:

Month	$\bar{H}_t$
Jan	31132.2
Feb	34407.1
Mar	32815.3
Apr	28962.4
May	24657.4
Jun	20269.4
Jul	22698.3
Aug	26937.2
Sep	30952.9
Oct	38399.0
Nov	34871.0
Dec	31693.9

90° tilt

Adding the vertical tilt data to the previous chart:



This graph shows the total solar radiation per square foot falling on both horizontal and vertical surfaces for each month of an average year.

Additional data for surfaces with 50° tilt, 35° tilt, and 20° tilt can be calculated and added to this graph to give a total picture of the relationship of tilt to available solar energy:

month	$\bar{H}$	$\bar{K}_t$	$\bar{R}$	TOTAL
Jan	743.9	.469	1.56	35975.0
Feb	1031.7	.499	1.42	42485.4
Mar	1323.2	.499	1.15	47172.0
Apr	1755.3	.543	.95	50026.0
May	1988.5	.554	.85	52396.9
Jun	2111.4	.563	.77	48773.3
Jul	2033.9	.552	.79	49810.2
Aug	1810.3	.538	.88	49384.9
Sep	1517.3	.527	1.07	48705.3
Oct	1202.6	.531	1.33	49583.1
Nov	908.1	.501	1.51	45495.8
Dec	690.8	.479	1.67	35762.7

50° tilt

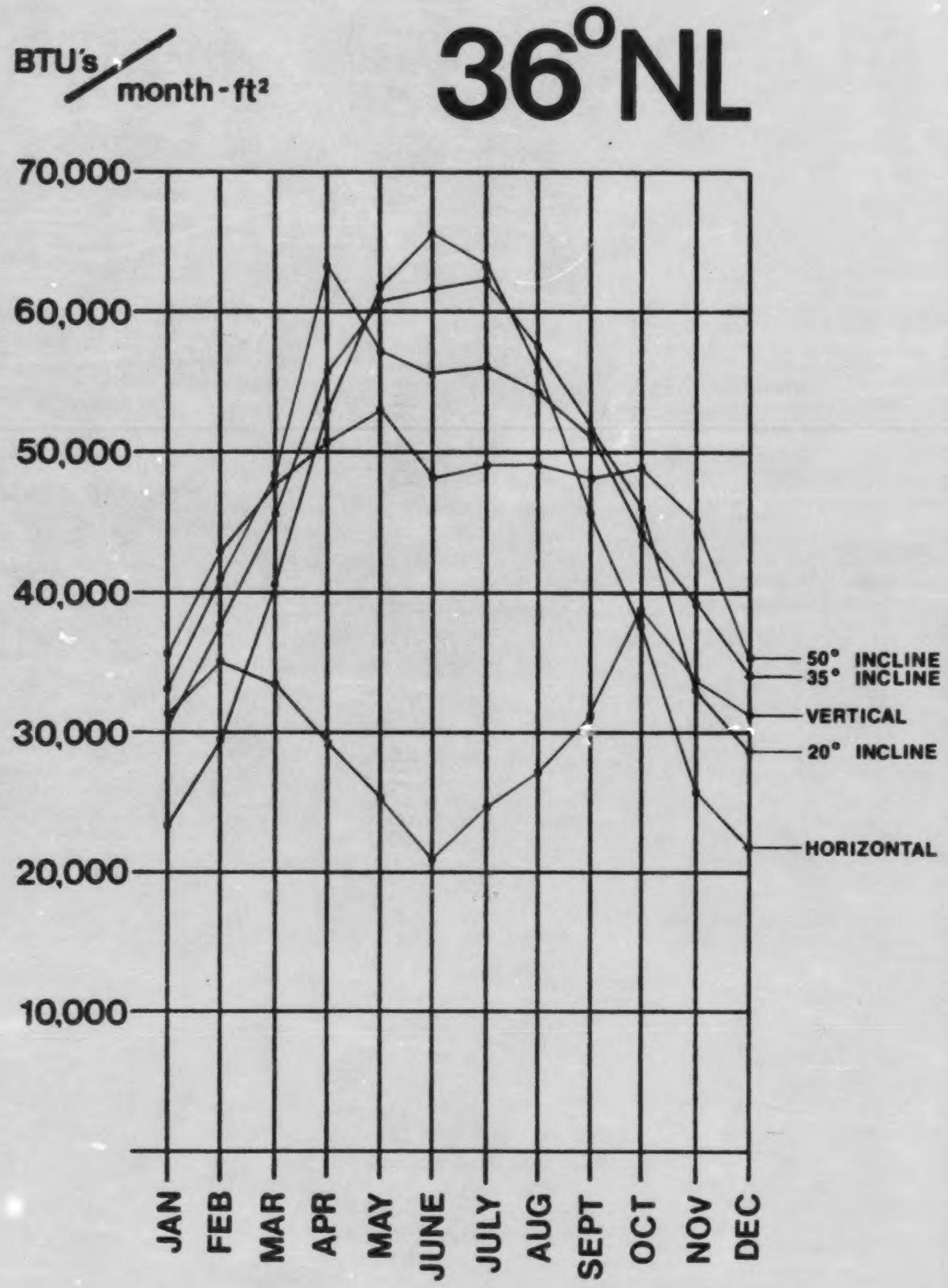
month	$\bar{H}$	$\bar{K}_t$	$\bar{R}$	TOTAL
Jan	743.9	.469	1.47	33899.5
Feb	1031.7	.499	1.37	40989.4
Mar	1323.2	.499	1.17	47992.4
Apr	1755.3	.543	1.03	63492.8
May	1988.5	.554	.93	57328.4
Jun	2111.4	.563	.88	55740.9
Jul	2033.9	.552	.90	56745.8
Aug	1810.3	.538	.98	54996.9
Sep	1517.3	.527	1.12	50981.2
Oct	1202.6	.531	1.33	44583.1
Nov	908.1	.501	1.45	39502.3
Dec	690.8	.479	1.63	34906.1

35° tilt

month	$\bar{H}$	$\bar{K}_t$	$\bar{R}$	TOTAL
Jan	743.9	.469	1.32	30440.5
Feb	1031.7	.499	1.27	37997.5
Mar	1323.2	.499	1.14	46761.8
Apr	1755.3	.543	1.00	55818.5
May	1988.5	.554	.98	60404.5
Jun	2111.4	.563	.96	60808.3
Jul	2033.9	.552	.97	61159.3
Aug	1810.3	.538	1.03	57802.8
Sep	1517.3	.527	1.12	50981.2
Oct	1202.6	.531	1.23	45855.1
Nov	908.1	.501	1.22	33236.4
Dec	690.8	.479	1.37	29338.2

20° tilt

Imposing all five sets of data onto the same graph will show the relationships of solar absorption to the incline of surface.



36°NL

The data for tilted surfaces demonstrates why attics are extremely hot during the summer time, in most conventional housing. The walls and windows (vertical angle) of a typical home, on the other hand, are extremely efficient and well suited to summer conditions.

I. Data should be analyzed and compared to the requirements of the area. Surface orientation should be selected so that solar collection is minimized during warm months and maximized during cold seasons.

J. During winter months the majority of useful solar radiation falls between 9:30 A.M. to 3:00 P.M. To insure the effectiveness of a solar structure, adjacent areas should be free of any obstructions which would prevent or reduce solar gain during months with outside temperatures below the comfort range (68°F-78°F). This does not mean that an area need be completely free of vegetation or other structures. Overhang is an obstruction to summer solar gain, but still permits sunlight to enter during winter. (See Figures 12.08 & 12.09)

47

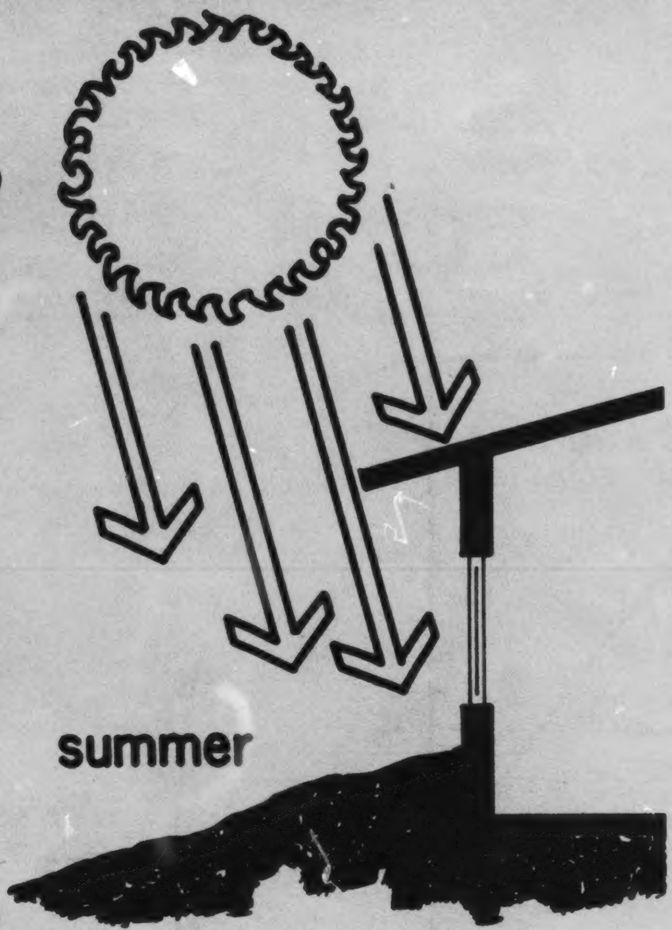


fig. 12.08

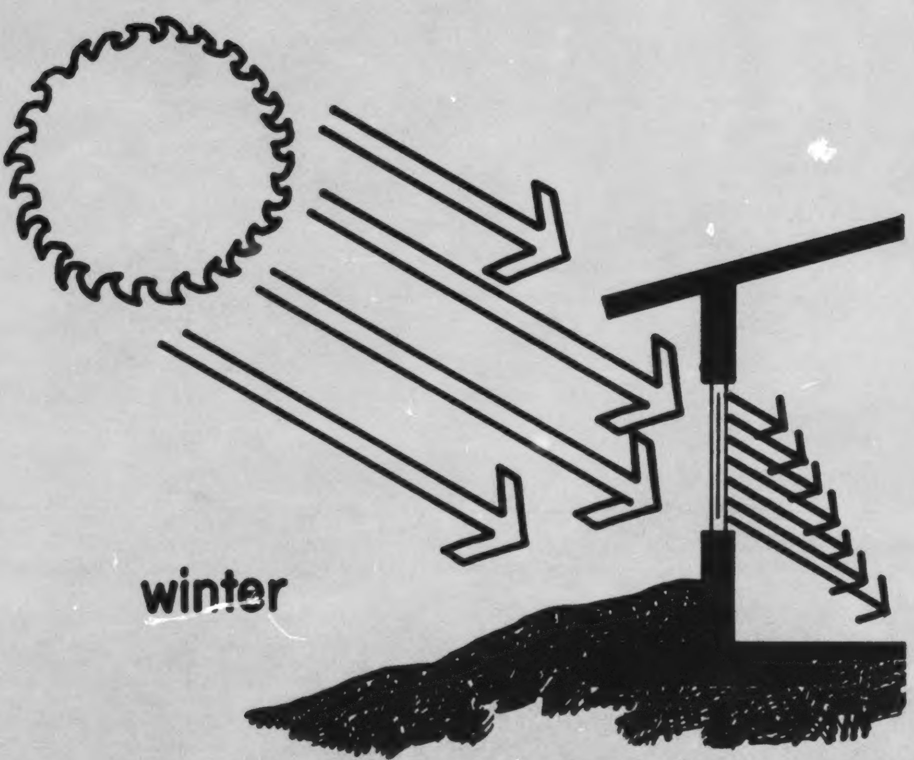


fig. 12.09

K. A tool used to determine the position and height of objects in relation to the solar path and angle is called a sun chart. Sun charts for various latitude positions are included at the end of this section. Each chart shows the path and azimuth (angle) of the sun for each month. Each path includes the sun's movement from sunrise to sunset. (See Figure 12.10)

Example: 36^0 North Latitude

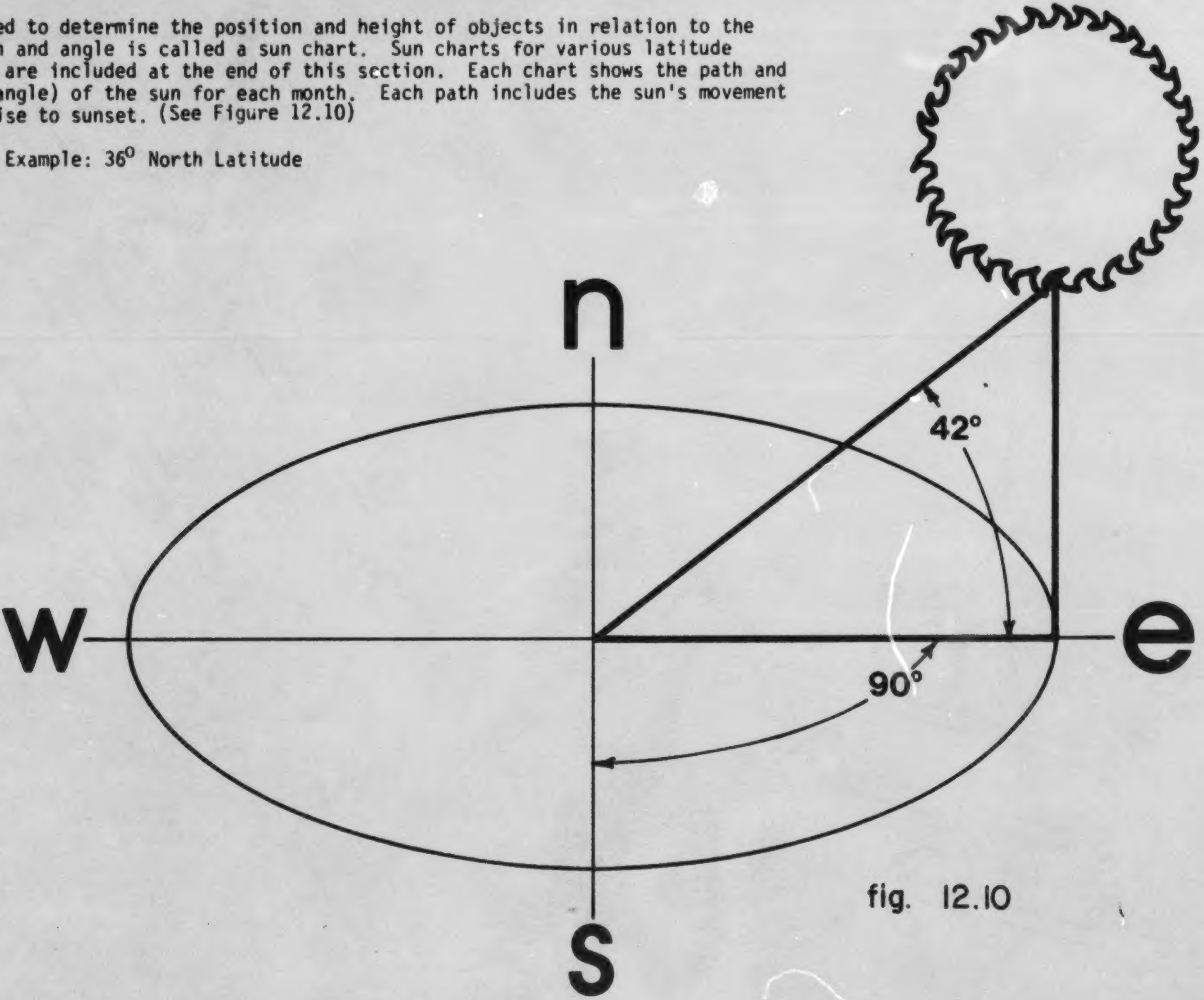


fig. 12.10

Combining the altitude and azimuth angles locates the sun on the chart. The sun's position tells us that the date is June 21 and the time is about 8:25 A.M.

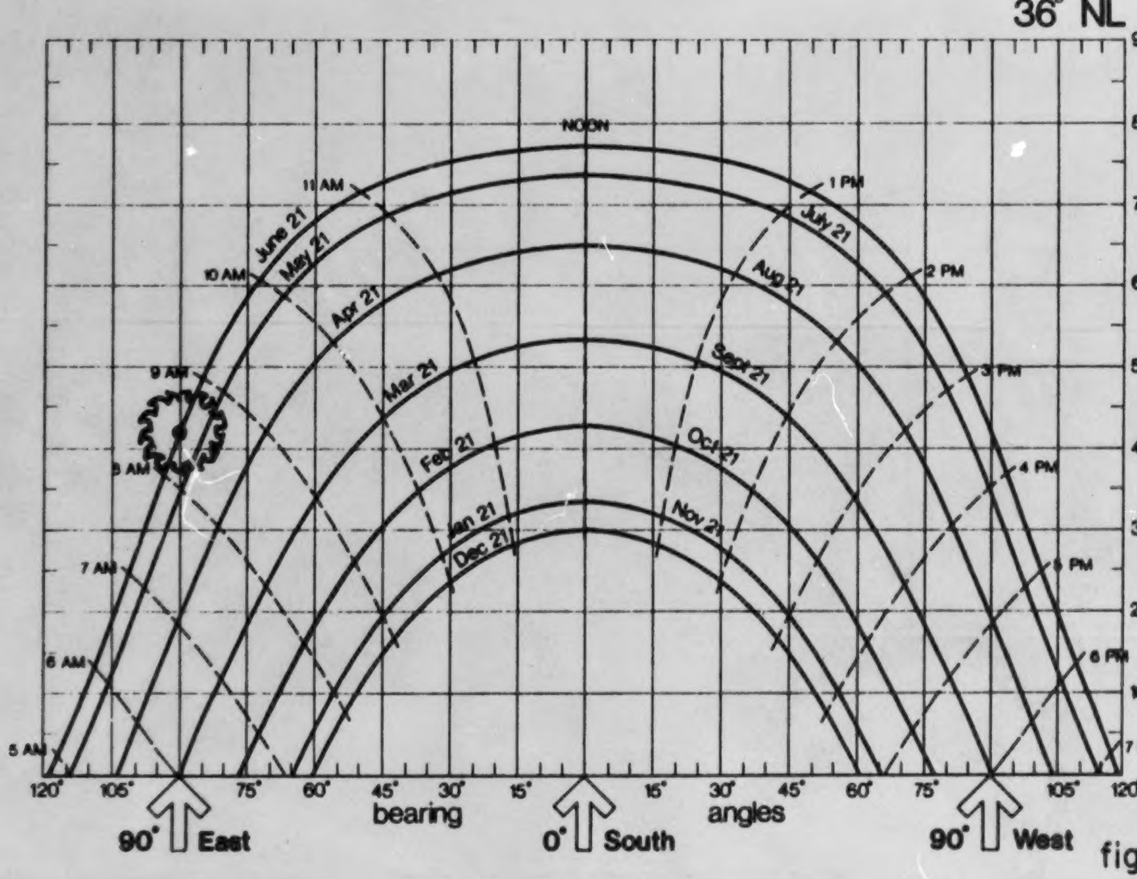


fig. 12.11

L. Determining the position and height of obstructions on the sun chart will give the months and times of day during which your reference point will be obstructed from the sun's rays.
To plot the skyline:

1. Stand at the position where the proposed building is to be located(reference point).
   To get a general feel of the site in terms of solar access, a single reference point will work.
2. Mark the reference point with a rock, stick, golf tee, etc.
3. Using a common compass, find magnetic south.
4. Correct the orientation(using the chart on page 19 of the core section) so that you are facing true south(solar south).
   Mark the position of true south in relation to your reference point.
5. Knowing the true south direction and the reference point, mark also the north, east, and west directions.
6. You are now ready to translate the surrounding site features onto the sun chart.
7. First, locate objects which are closest to the reference point.
   You need only locate objects which lie to the east, south, and west directions from the reference point.
8. Using the compass, stand at the reference point and pick an object on the east/south/west horizon.
   Which axis is that object closest to (east? west? south?)
   In figure 12.12, for example, notice the building close to the west axis.
   One corner of the structure lies on the west axis. The other corner lies 20 degrees south of true west.
   Mark these two coordinates on your sun chart(see figure 12.14)
   Follow this same process to locate other objects.
9. Now calculate the height of the building.
   Standing at the reference point, look straight at the building.
   Now, raise your line of sight to the top(roof) of that structure.
   How many degrees difference is there between a level line of sight and a line of sight directed at the roof? (Estimate)
   In this instance(see figure 12.13) only 10 degrees of angle exists between eye level and an immaginary line touching the top of the roof.
   Mark this on the sun chart as well.
10. You can now approximate the height and location of that structure on the sun chart.
11. Follow this process to locate and calculate the rough height of other objects.
12. Remember, perfection is not necessary. We are merely trying to estimate the location of relative objects in order to determine how they will affect the amount of sunlight the reference point will receive and during what times of the year this will come into play.

M. This diagram shows how a compass can be used to graph the size (length) of an object by taking two readings: one reading taken by locating the extreme left of the shape and one taken from the right hand margin. (See Figure 12.12)

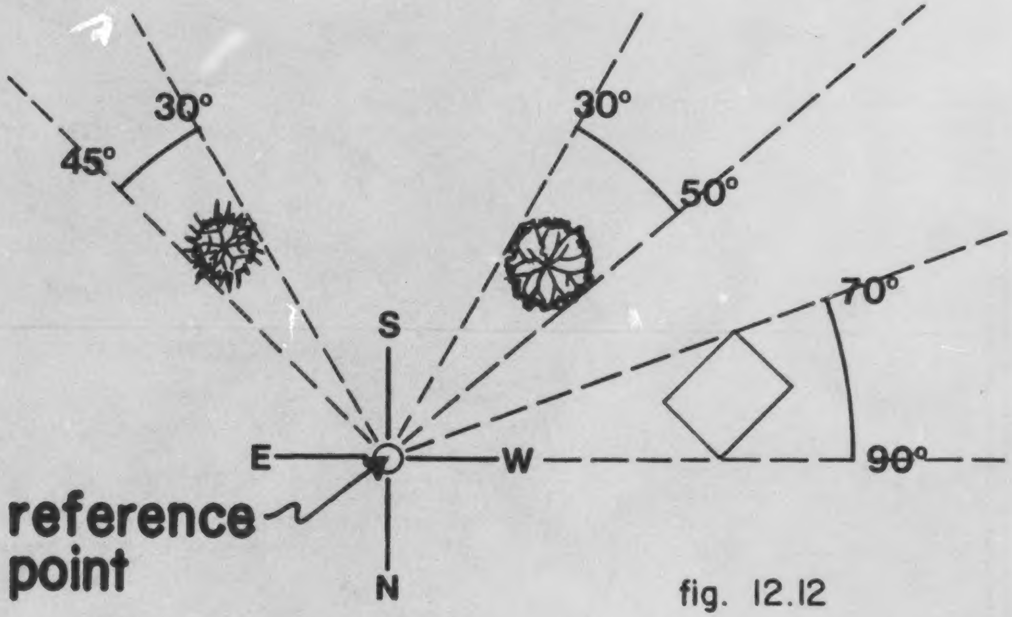

30°
45°
30°
50°
70°
S
E
W
90°
reference point
N

fig. 12.12

N. This diagram demonstrates how to determine the height of an object by estimating the angle it makes to an imaginary horizontal plane located at eye level. (See Figure 12.13)

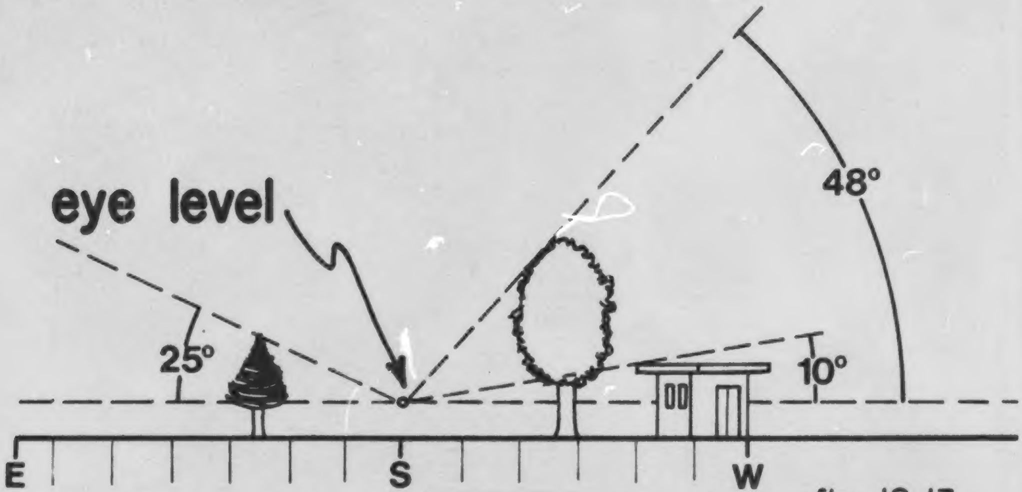

48°
eye level
25°
10°
E
S
W

fig. 12.13

0. Imposing the objects onto the sun chart, shows only the large tree as an obstruction to solar gain in the winter months. This tree is deciduous, however, and should be indicated with a dotted line since it drops its leaves at the beginning of the cold season (close groupings of deciduous trees will pose an obstruction to solar gain, even in the winter). (See Figure 12.14)

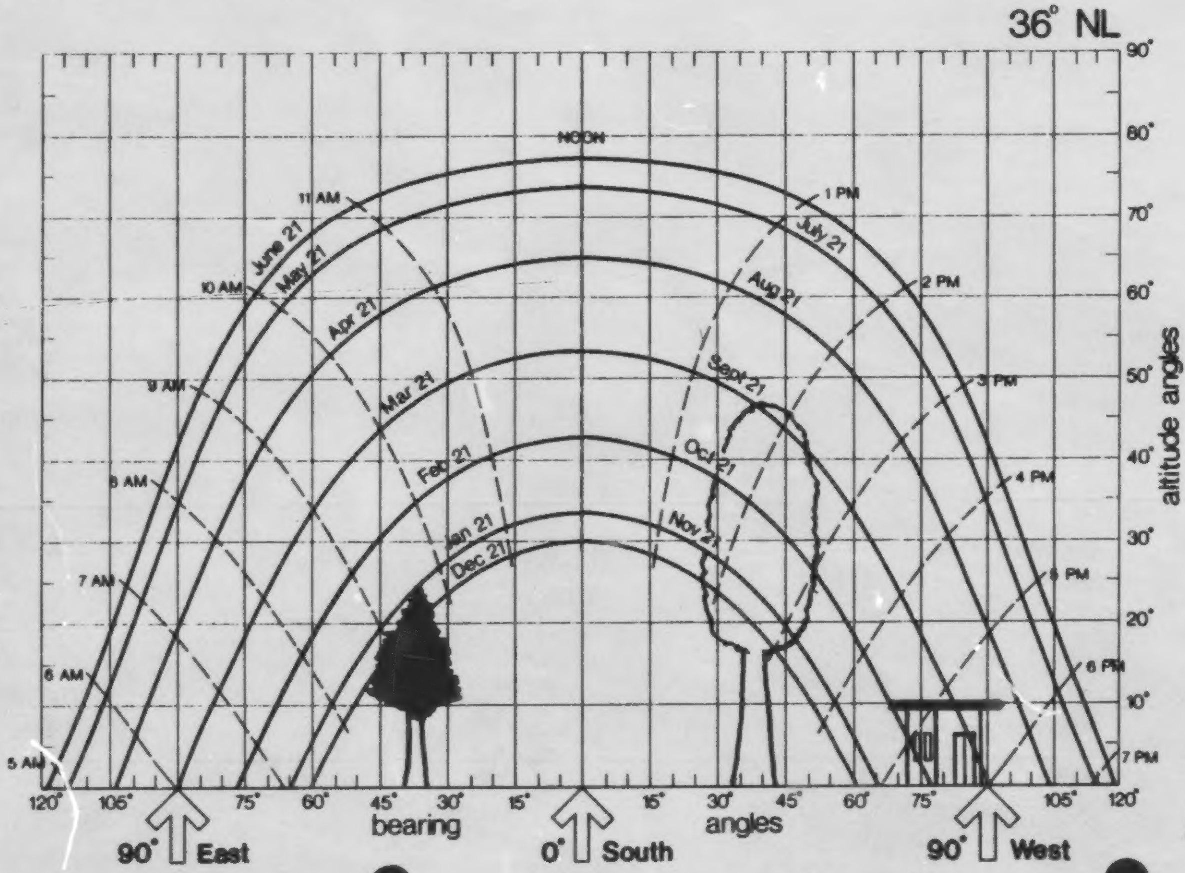
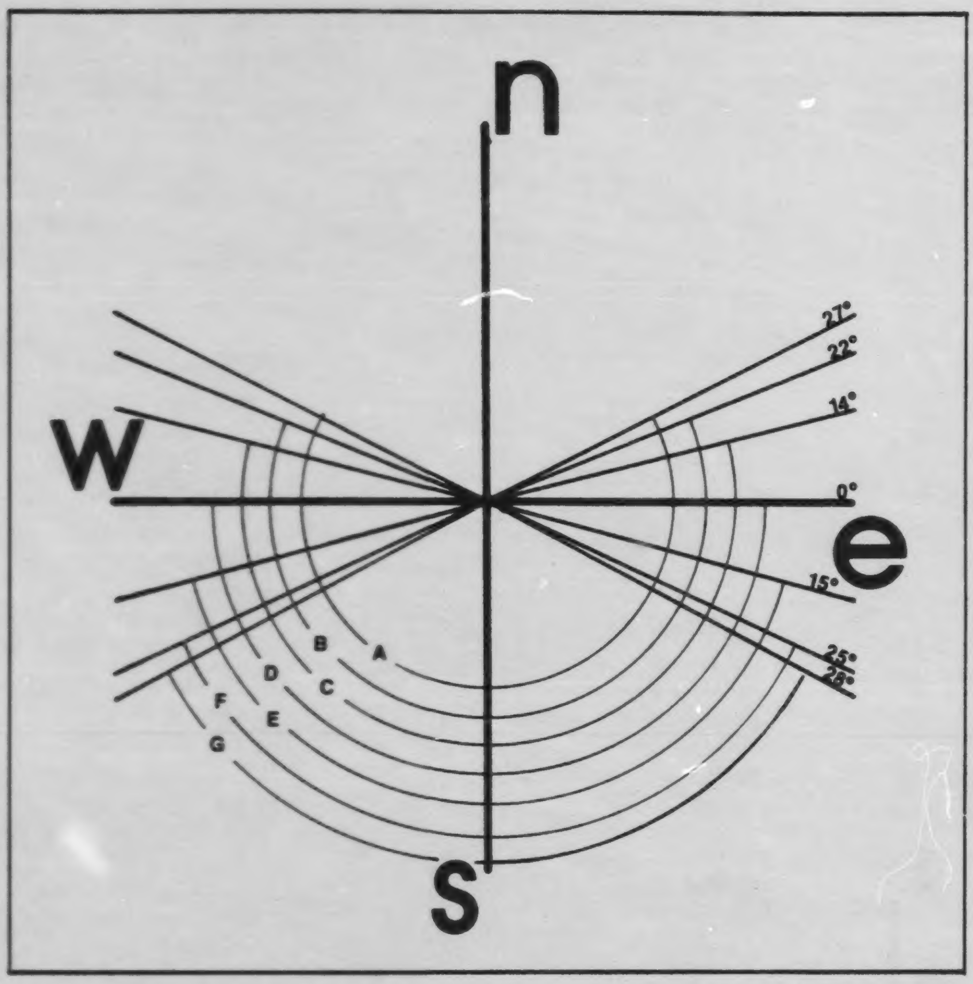


fig. 12.14

azimuth / altitude data

azimuth


n
w
e
s
27°
22°
14°
0°
15°
25°
28°
A
B
C
D
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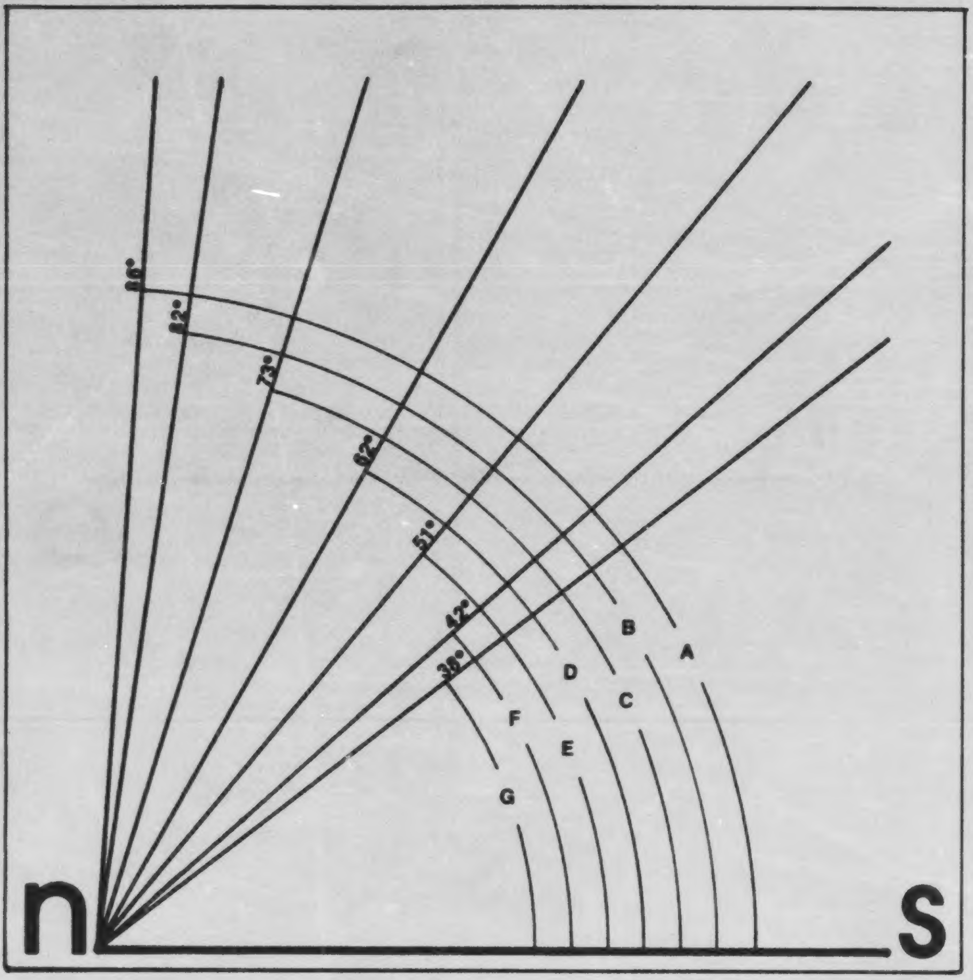
F
G

A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

28° NL

altitude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73°
62°
51°
42°
38°
A
B
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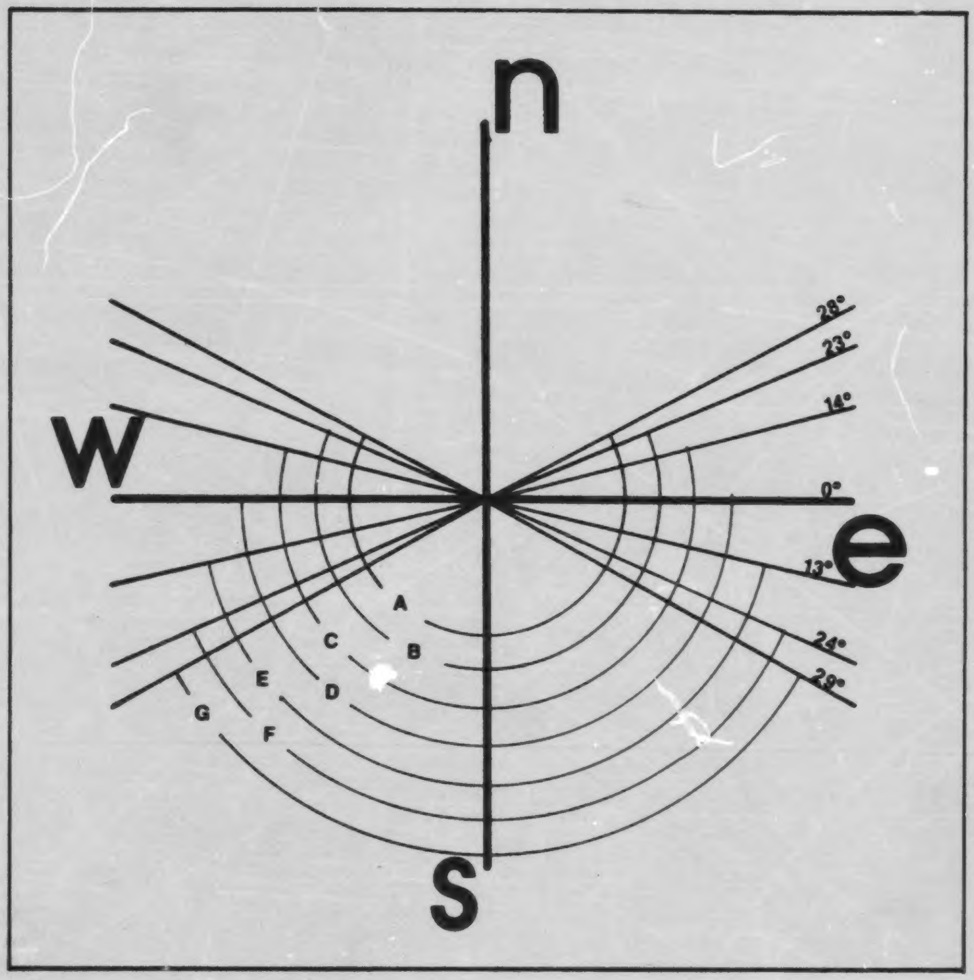
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

28° NL

azimuth


n
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28°
23°
14°
0°
13°
24°
29°
A
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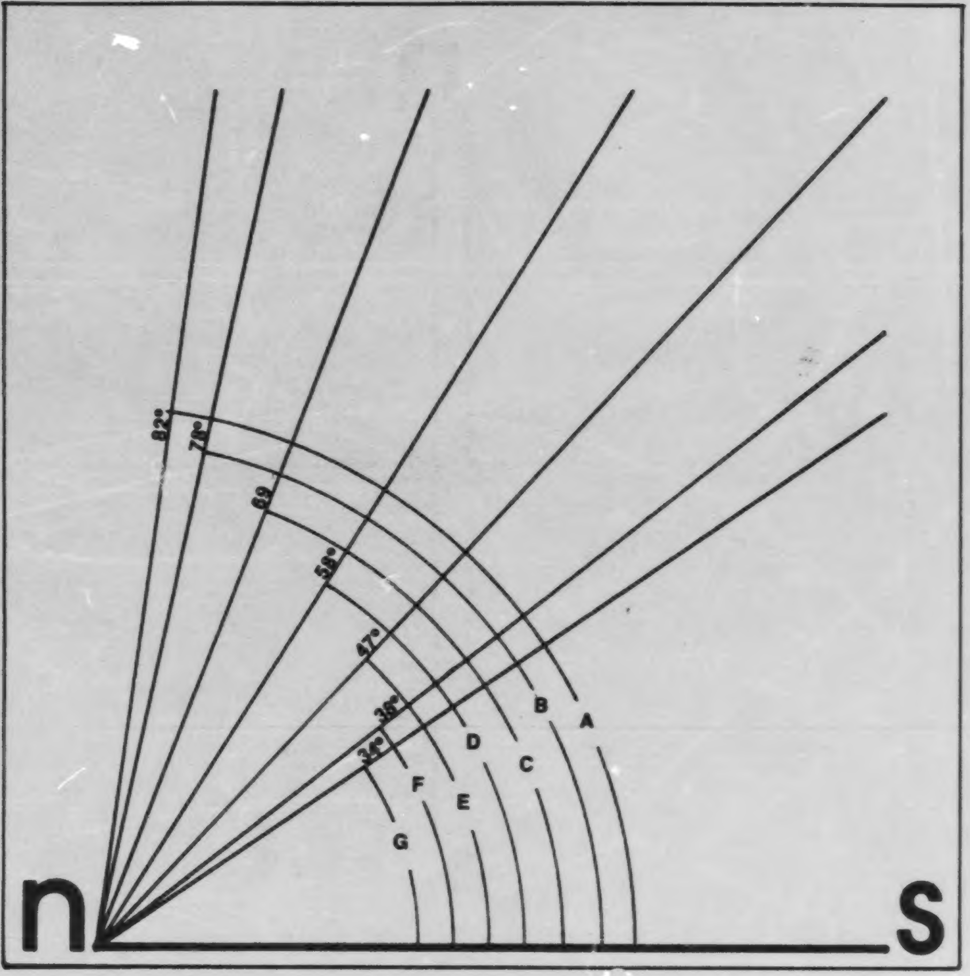
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

32° NL

60

altitude


82°
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69
58°
47°
36°
34°
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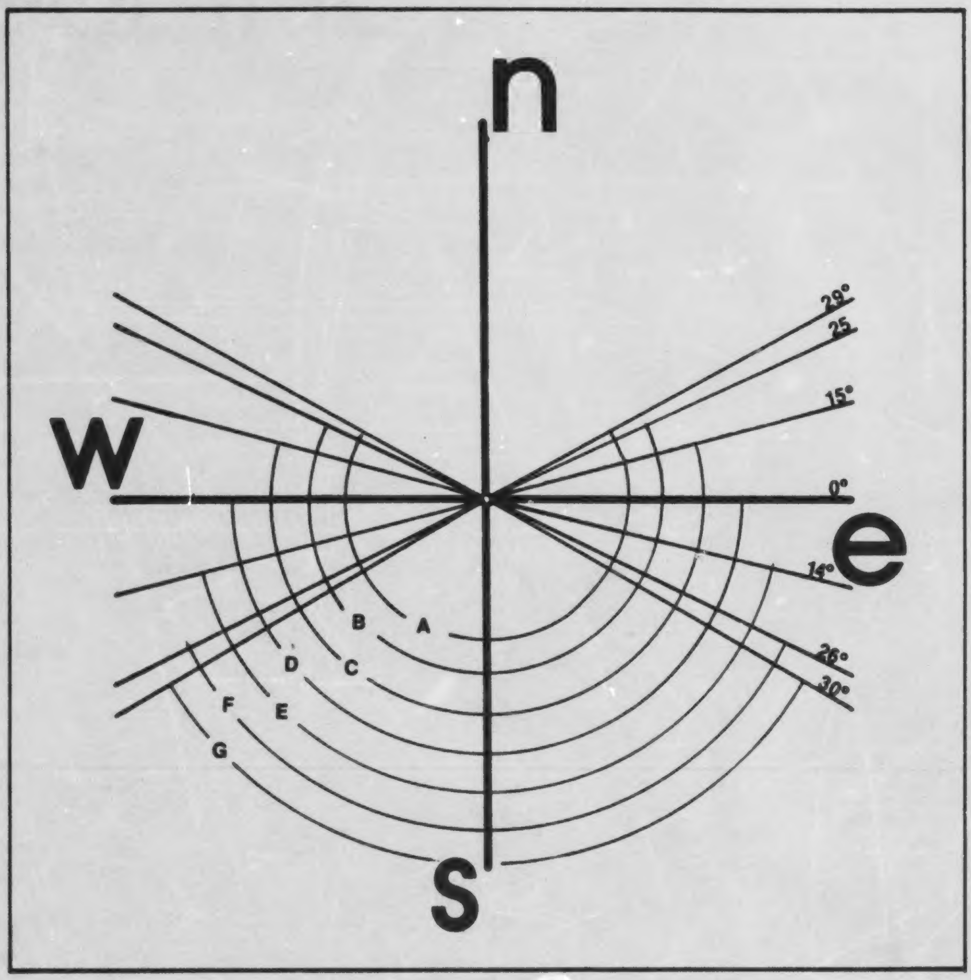
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

32° NL

azimuth


n
w
e
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29°
25
15°
0°
14°
26°
30°
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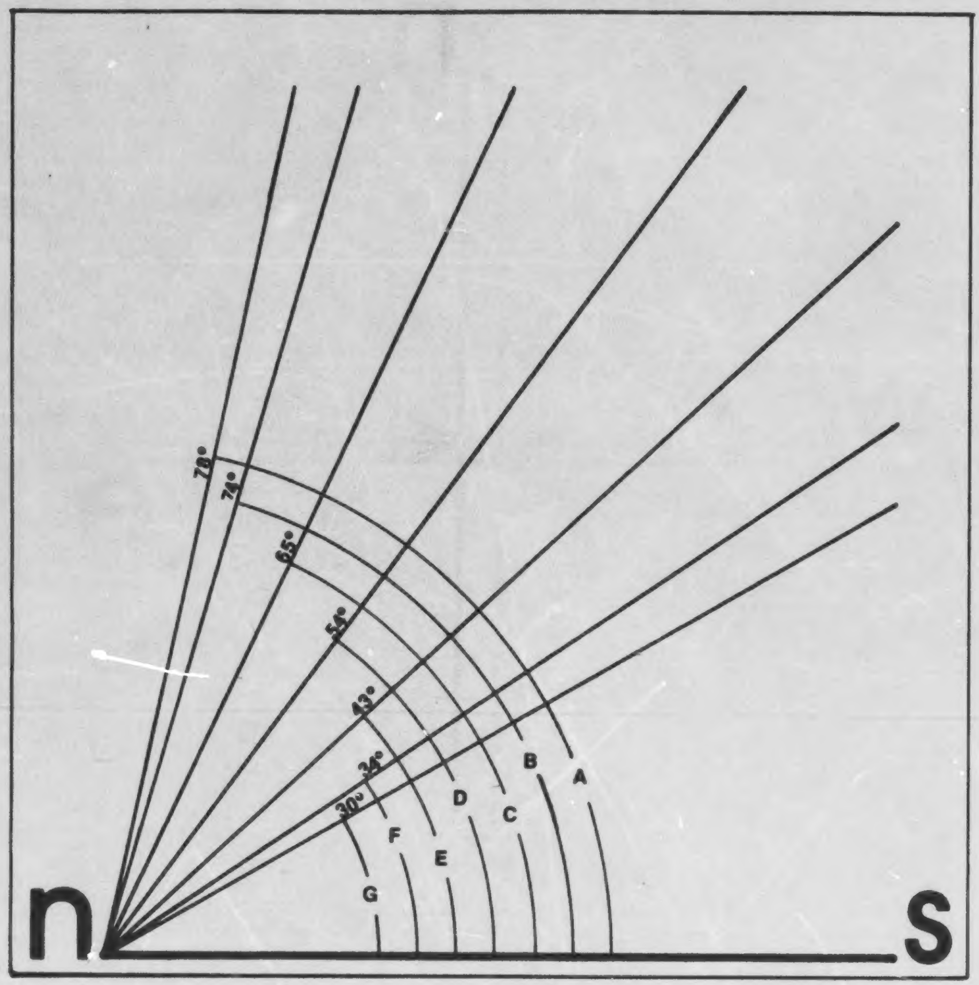
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

36° NL

altitude

36° NL



78°
74°
65°
54°
43°
34°
30°
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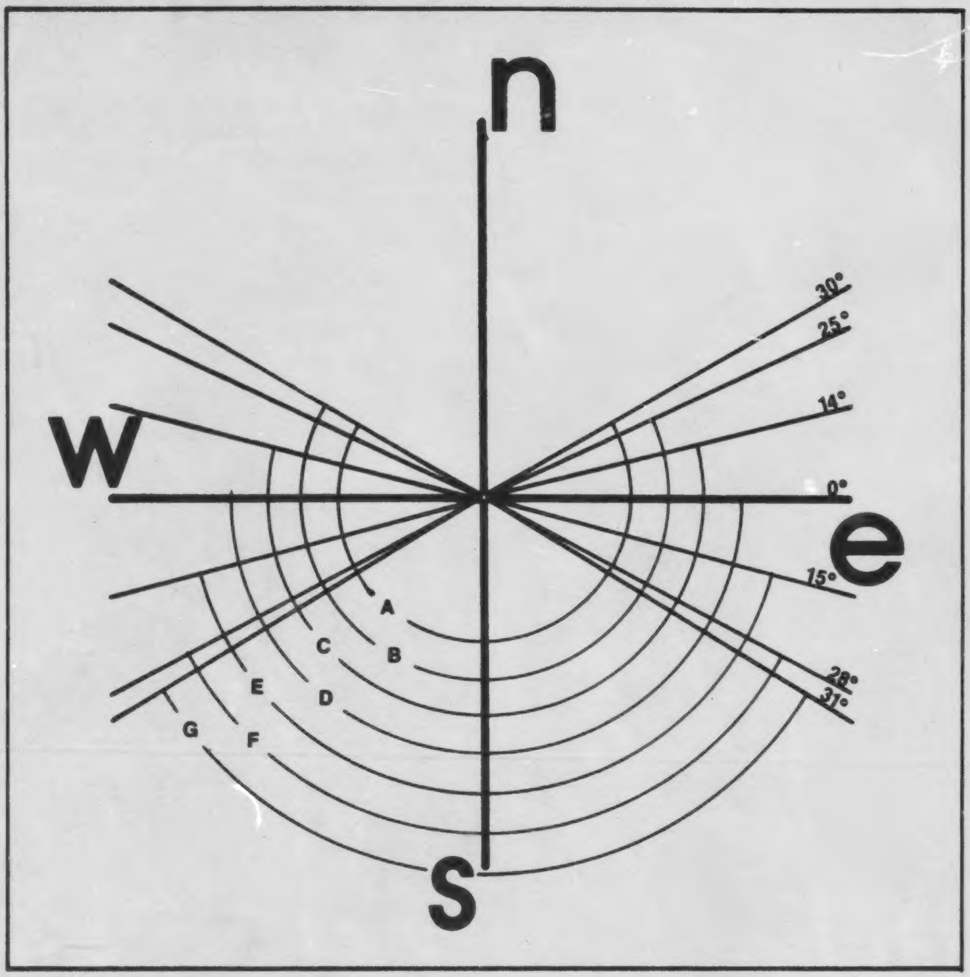
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

azimuth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0°
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28°
31°
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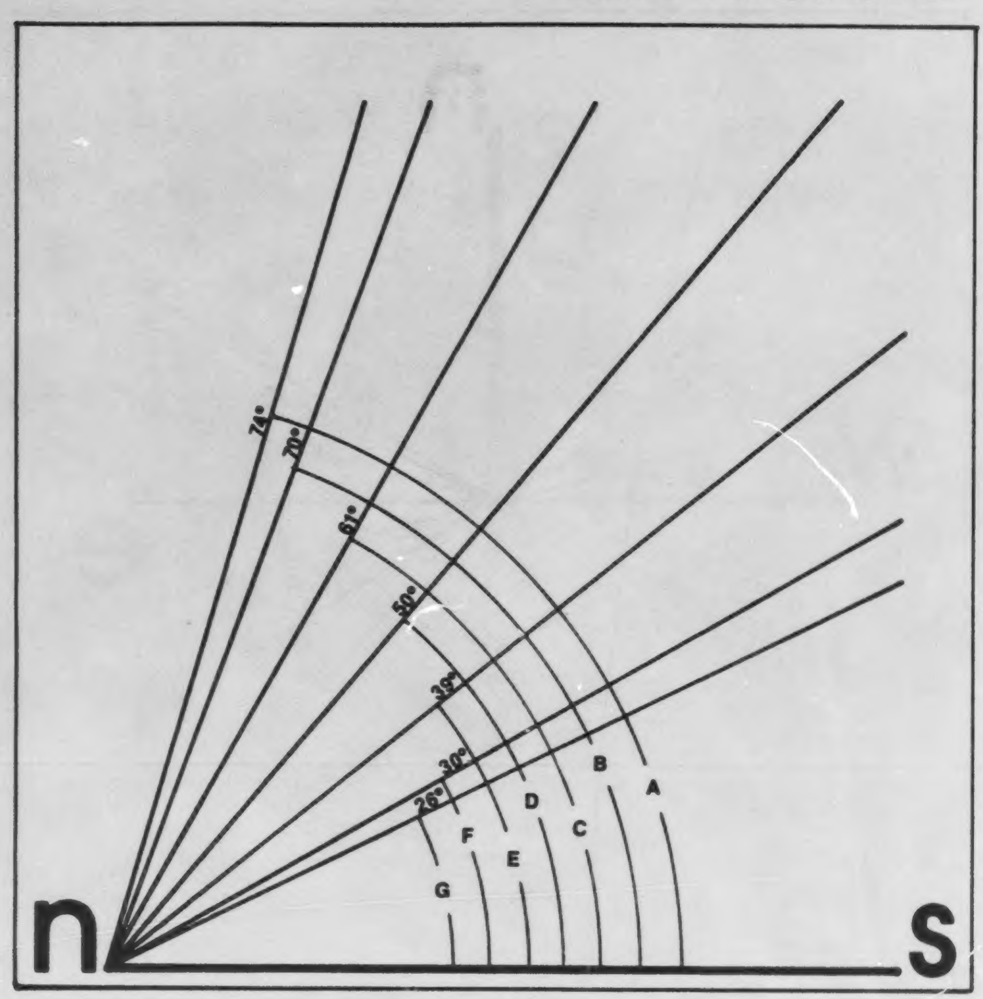
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

40° NL

altitude


74°
70°
61°
50°
39°
30°
26°
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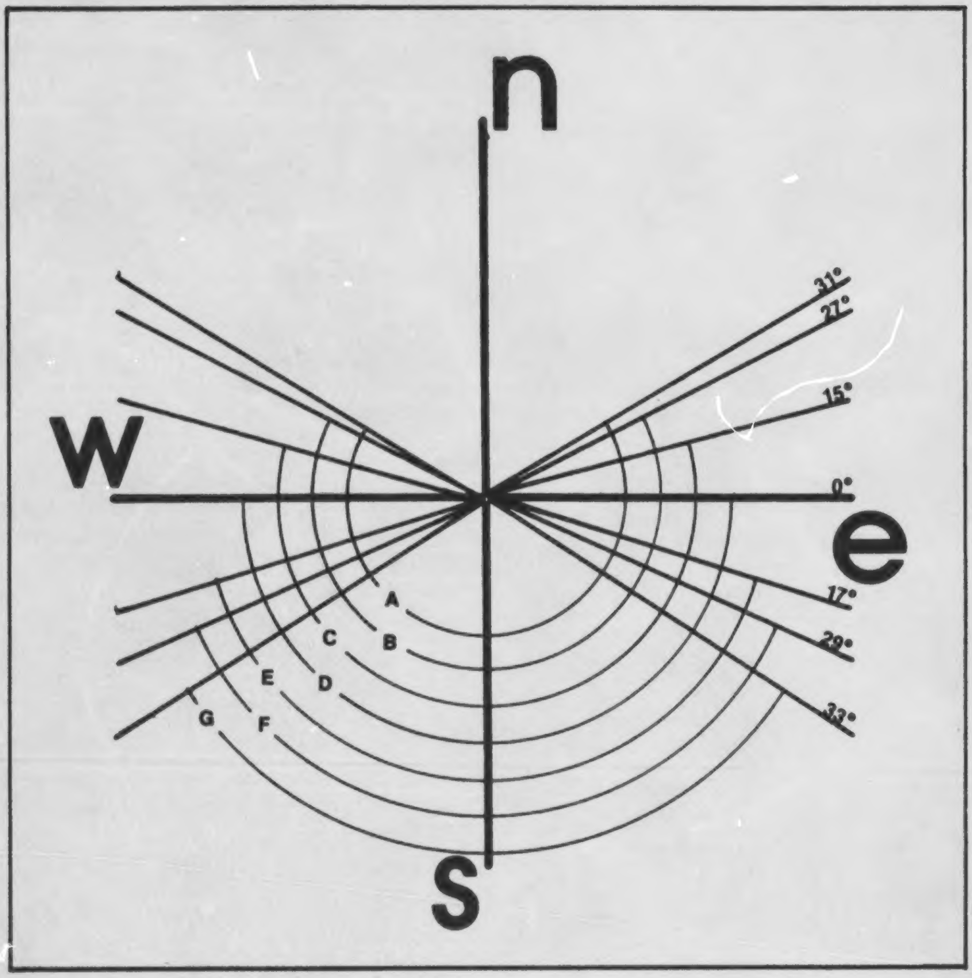
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

40° NL

azimuth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31°
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33°
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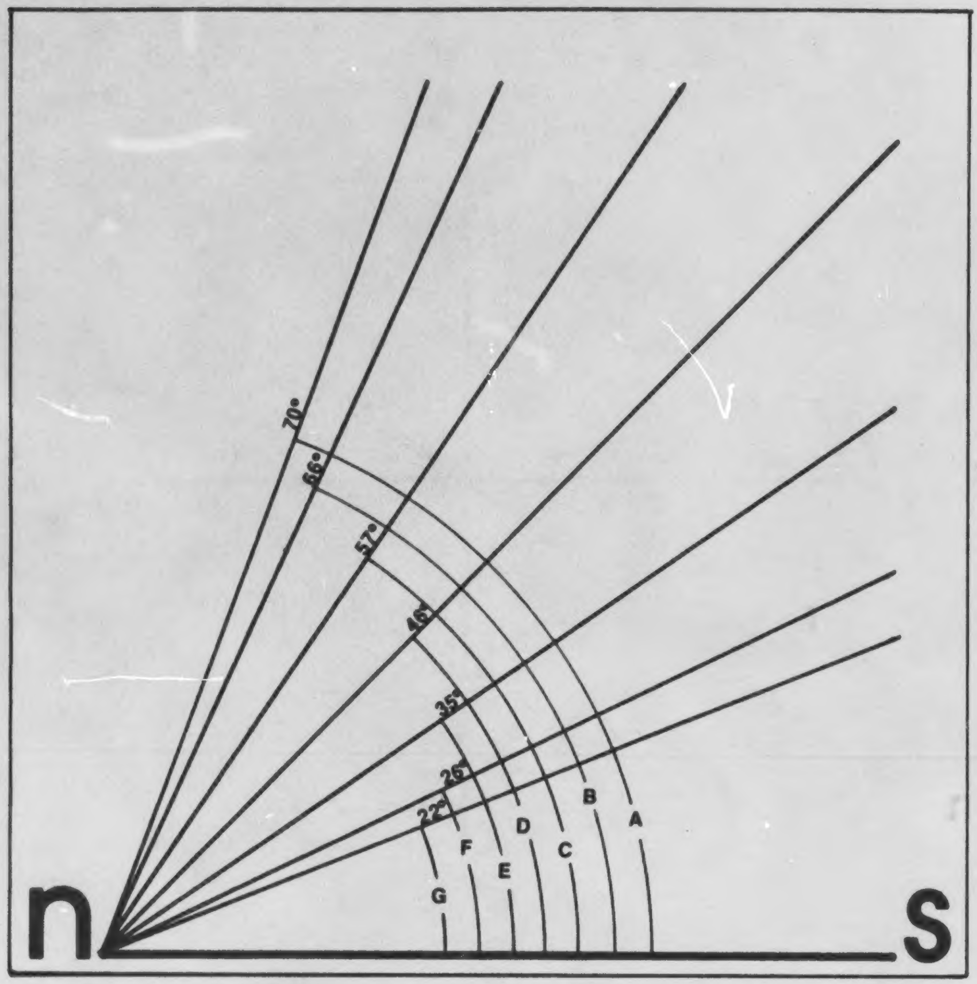
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

44° NL

66

altitude


70°
66°
57°
46°
35°
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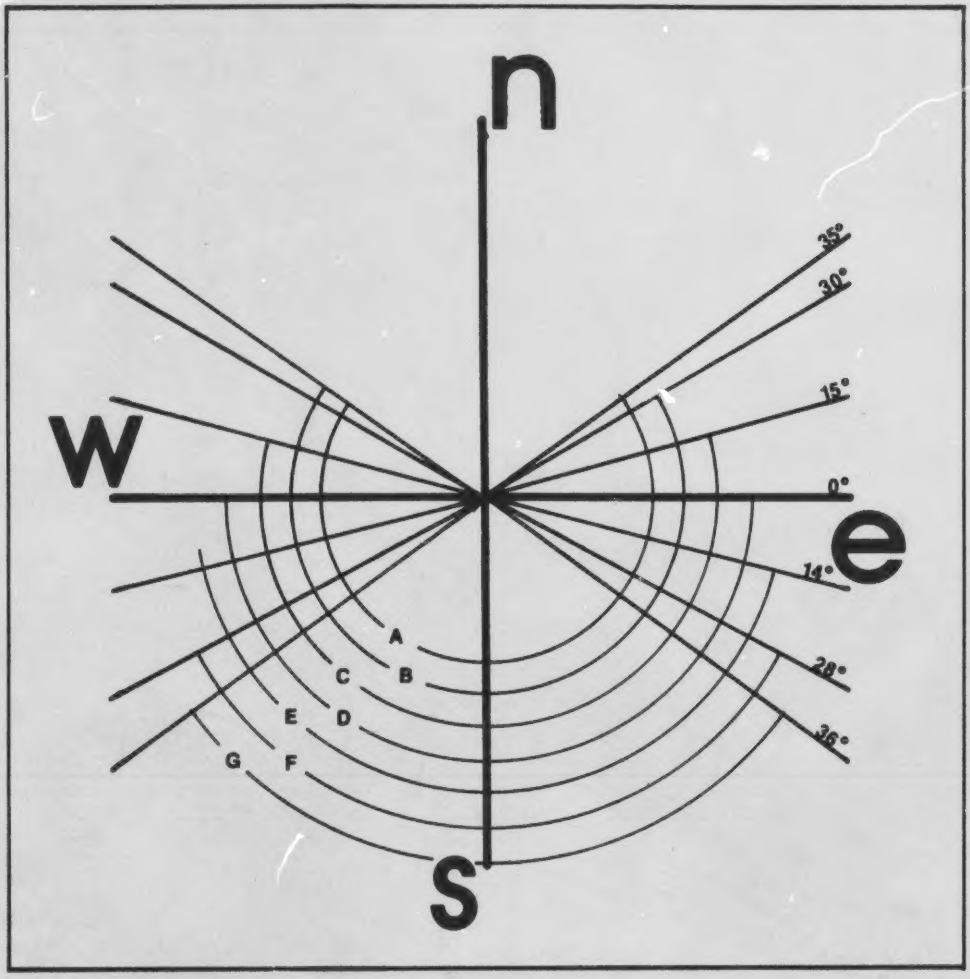
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

44° NL

azimuth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35°
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36°
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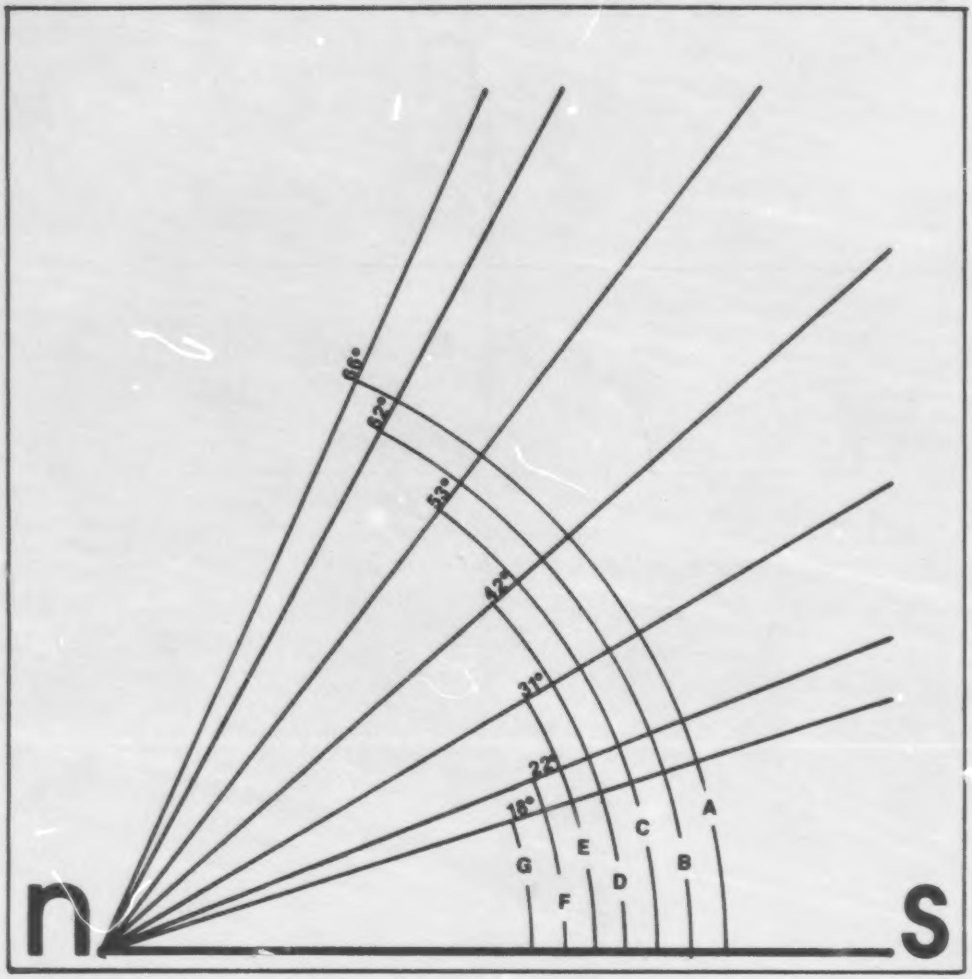
A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

48° NL

altitude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62°
53°
42°
31°
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A. JUNE 22
B. MAY 22 JULY 22
C. APRIL 22 AUGUST 22
D. MARCH 22 SEPTEMBER 22
E. FEBRUARY 22 OCTOBER 22
F. JANUARY 22 NOVEMBER 22
G. DECEMBER 22

48° NL

solar data for horizontal surfaces

RADIATION AND OTHER DATA FOR 80 LOCATIONS IN THE UNITED STATES AND CANADA ($\bar{H}$ = Monthly average daily total radiation on a horizontal surface, Btu/day-ft^2; $\bar{K}_t$ = the fraction of the extra terrestrial radiation transmitted through the atmosphere; t_o = ambient temperature, deg F.)

		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Albuquerque, N. M.	$\bar{H}$	1150.9	1453.9	1925.4	2343.5	2560.9	2757.5	2561.2	2387.8	2120.3	1639.8	1274.2	1061.6
Lat. 35°03′ N.	$\bar{K}_t$	0.704	0.691	0.719	0.722	0.713	0.737	0.695	0.708	0.728	0.711	0.684	0.704
El. 5314 ft	t_o	37.3	43.3	50.1	59.6	69.4	79.1	82.8	80.6	73.6	62.1	47.8	39.4
Annette Is., Alaska	$\bar{H}$	236.2	428.4	883.4	1357.2	1634.7	1638.7	1632.1	1269.4	962	454.6	220.3	152
Lat. 55°02′ N.	$\bar{K}_t$	0.427	0.415	0.492	0.507	0.484	0.441	0.454	0.427	0.449	0.347	0.304	0.361
El. 110 ft	t_o	35.8	37.5	39.7	44.4	51.0	56.2	58.6	59.8	54.8	48.2	41.9	37.4
Apalachicola, Florida	$\bar{H}$	1107	1378.2	1654.2	2040.9	2268.6	2195.9	1978.6	1912.9	1703.3	1544.6	1243.2	982.3
Lat. 29°45′ N.	$\bar{K}_t$	0.577	0.584	0.576	0.612	0.630	0.594	0.542	0.558	0.559	0.608	0.574	0.543
El. 35 ft	t_o	57.3	59.0	62.9	69.5	76.4	81.8	83.1	83.1	80.6	73.2	65.7	58.5
Astoria, Oregon	$\bar{H}$	338.4	607	1008.5	1401.5	1838.7	1753.5	2007.7	1721	1322.5	780.4	413.6	295.2
Lat. 46°12′ N.	$\bar{K}_t$	0.330	0.397	0.454	0.471	0.524	0.466	0.551	0.538	0.526	0.435	0.336	0.332
El. 8 ft	t_o	41.3	44.7	46.9	51.3	55.0	59.3	62.6	63.6	62.2	55.7	48.5	43.9
Atlanta, Georgia	$\bar{H}$	848	1080.1	1426.9	1807	2018.1	2102.6	2002.9	1898.1	1519.2	1290.8	997.8	751.6
Lat. 33°39′ N.	$\bar{K}_t$	0.493	0.496	0.522	0.551	0.561	0.564	0.545	0.559	0.515	0.543	0.510	0.474
El. 976 ft	t_o	47.2	49.6	55.9	65.0	73.2	80.9	82.4	81.6	77.4	66.5	54.8	47.7
Barrow, Alaska	$\bar{H}$	13.3	143.2	713.3	1491.5	1883	2055.3	1602.2	953.5	428.4	152.4	22.9	—
Lat. 71°20′ N.	$\bar{K}_t$	—	0.776	0.773	0.726	0.553	0.533	0.448	0.377	0.315	0.35	—	—
El. 22 ft	t_o	−13.2	−15.9	−12.7	2.1	20.5	35.4	41.6	40.0	31.7	18.6	2.6	−8.6
Bismarck, N. D.	$\bar{H}$	587.4	934.3	1328.4	1668.2	2056.1	2173.8	2305.5	1929.1	1441.3	1018.1	600.4	464.2
Lat. 46°47′ N.	$\bar{K}_t$	0.594	0.628	0.606	0.565	0.588	0.579	0.634	0.606	0.581	0.584	0.510	0.547
El. 1660 ft	t_o	12.4	15.9	29.7	46.6	58.6	67.9	76.1	73.5	61.6	49.6	31.4	18.4
Blue Hill, Mass.	$\bar{H}$	555.3	797	1143.9	1438	1776.4	1943.9	1881.5	1622.1	1314	941	592.2	482.3
Lat. 42°13′ N.	$\bar{K}_t$	0.445	0.458	0.477	0.464	0.501	0.516	0.513	0.495	0.492	0.472	0.406	0.436
El. 629 ft	t_o	28.3	28.3	36.9	46.9	58.5	67.2	72.3	70.6	64.2	54.1	43.3	31.5
Boise, Idaho	$\bar{H}$	518.8	884.9	1280.4	1814.4	2189.3	2376.7	2500.3	2149.4	1717.7	1128.4	678.6	456.8
Lat. 43°34′ N.	$\bar{K}_t$	0.446	0.533	0.548	0.594	0.619	0.631	0.684	0.660	0.656	0.588	0.494	0.442
El. 2844 ft	t_o	29.5	36.5	45.0	53.5	62.1	69.3	79.6	77.2	66.7	56.3	42.3	33.1
Boston, Mass.	$\bar{H}$	505.5	738	1067.1	1355	1769	1864	1860.5	1570.1	1267.5	896.7	635.8	442.8
Lat. 42°22′ N.	$\bar{K}_t$	0.410	0.426	0.445	0.438	0.499	0.495	0.507	0.480	0.477	0.453	0.372	0.400
El. 29 ft.	t_o	31.4	31.4	39.9	49.5	60.4	69.8	74.5	73.8	66.8	57.4	46.6	34.9
Brownsville, Texas	$\bar{H}$	1105.9	1262.7	1505.9	1714	2092.2	2288.5	2345	2124	1774.9	1536.5	1104.8	982.3
Lat. 25°55′ N.	$\bar{K}_t$	0.517	0.500	0.506	0.509	0.584	0.627	0.650	0.617	0.566	0.570	0.468	0.488
El. 20 ft	t_o	62.3	66.7	70.7	76.2	81.4	85.1	86.5	86.9	84.1	78.9	70.7	65.2
Caribou, Maine	$\bar{H}$	497	861.6	1360.1	1495.9	1779.7	1779.7	1898.1	1675.6	1254.6	793	415.5	398.9
Lat. 46°52′ N.	$\bar{K}_t$	0.504	0.579	0.619	0.507	0.509	0.473	0.522	0.527	0.506	0.455	0.352	0.470
El. 628 ft	t_o	11.5	12.8	24.4	37.3	51.8	61.6	67.2	65.0	56.2	44.7	31.3	16.8
Charleston, S. C.	$\bar{H}$	946.1	1152.8	1352.4	1918.8	2063.4	2113.3	1649.4	1933.6	1557.2	1332.1	1073.8	952
Lat. 32°54′ N.	$\bar{K}_t$	0.541	0.521	0.491	0.584	0.574	0.567	0.454	0.569	0.525	0.554	0.539	0.586
El. 46 ft	t_o	53.6	55.2	60.6	67.8	74.8	80.9	82.9	82.3	79.1	69.8	59.8	54.0
Cleveland, Ohio	$\bar{H}$	466.8	681.9	1207	1443.9	1928.4	2102.6	2094.4	1840.6	1410.3	997	526.8	427.3
Lat. 41°24′ N.	$\bar{K}_t$	0.361	0.383	0.497	0.464	0.543	0.559	0.571	0.569	0.524	0.491	0.351	0.371
El. 805 ft.	t_o	30.8	30.9	39.4	50.2	62.4	72.7	77.0	75.1	68.5	57.4	44.0	32.8
Columbia, Mo.	$\bar{H}$	651.3	941.3	1315.8	1631.3	1999.6	2129.1	2148.7	1953.1	1689.6	1202.6	839.5	590.4
Lat. 38°58′ N.	$\bar{K}_t$	0.458	0.492	0.520	0.514	0.559	0.566	0.585	0.588	0.606	0.562	0.510	0.457
El. 785 ft	t_o	32.5	36.5	45.9	57.7	66.7	75.9	81.1	79.4	71.9	61.4	46.1	35.8
Columbus, Ohio	$\bar{H}$	486.3	746.5	1112.5	1480.8	1839.1	(2111)	2041.3	1572.7	1189.3	919.5	479	430.2
Lat. 40°00′ N.	$\bar{K}_t$	0.356	0.401	0.447	0.470	0.515	(0.561)	0.555	0.475	0.433	0.441	0.302	0.351
El. 833 ft	t_o	32.1	33.7	42.7	53.5	64.4	74.2	78	75.9	70.1	58	44.5	34.0
Davis, Calif.	$\bar{H}$	599.2	945	1504	1959	2368.6	2619.2	2565.6	2287.8	1856.8	1288.5	795.6	550.5
Lat. 38°33′ N.	$\bar{K}_t$	0.416	0.490	0.591	0.617	0.662	0.697	0.697	0.687	0.664	0.598	0.477	0.421
El. 51 ft	t_o	47.6	52.1	56.8	63.1	69.6	75.7	81	79.4	76.7	67.8	57	48.7
Dodge City, Kan.	$\bar{H}$	953.1	1186.3	1565.7	1975.6	2126.5	2459.8	2400.7	2210.7	1841.7	1421	1065.3	873.8
Lat. 37°46′ N.	$\bar{K}_t$	0.639	0.596	0.606	0.618	0.594	0.655	0.652	0.663	0.654	0.650	0.625	0.652
El. 2592 ft	t_o	33.8	38.7	46.5	57.7	66.7	77.2	83.8	82.4	73.7	61.7	46.5	36.8
East Lansing, Michigan	$\bar{H}$	425.8	739.1	1086	1249.8	1732.8	1914	1884.5	1627.7	1303.3	891.5	473.1	379.7
Lat. 42°44′ N.	$\bar{K}_t$	0.35	0.431	0.456	0.406	0.489	0.508	0.514	0.498	0.493	0.456	0.333	0.349
El. 856 ft	t_o	26.0	26.4	35.7	48.4	59.8	70.3	74.5	72.4	65.0	53.5	40.0	29.0

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* Liu, B.Y.H. and Jordan, R.C., "A Rational Procedure for Predicting The Long-Term Average Performance of Flat-Plate Solar-Energy Collectors," _Solar Energy_, Vol. 7, No. 2, pp. 71-74, 1963.

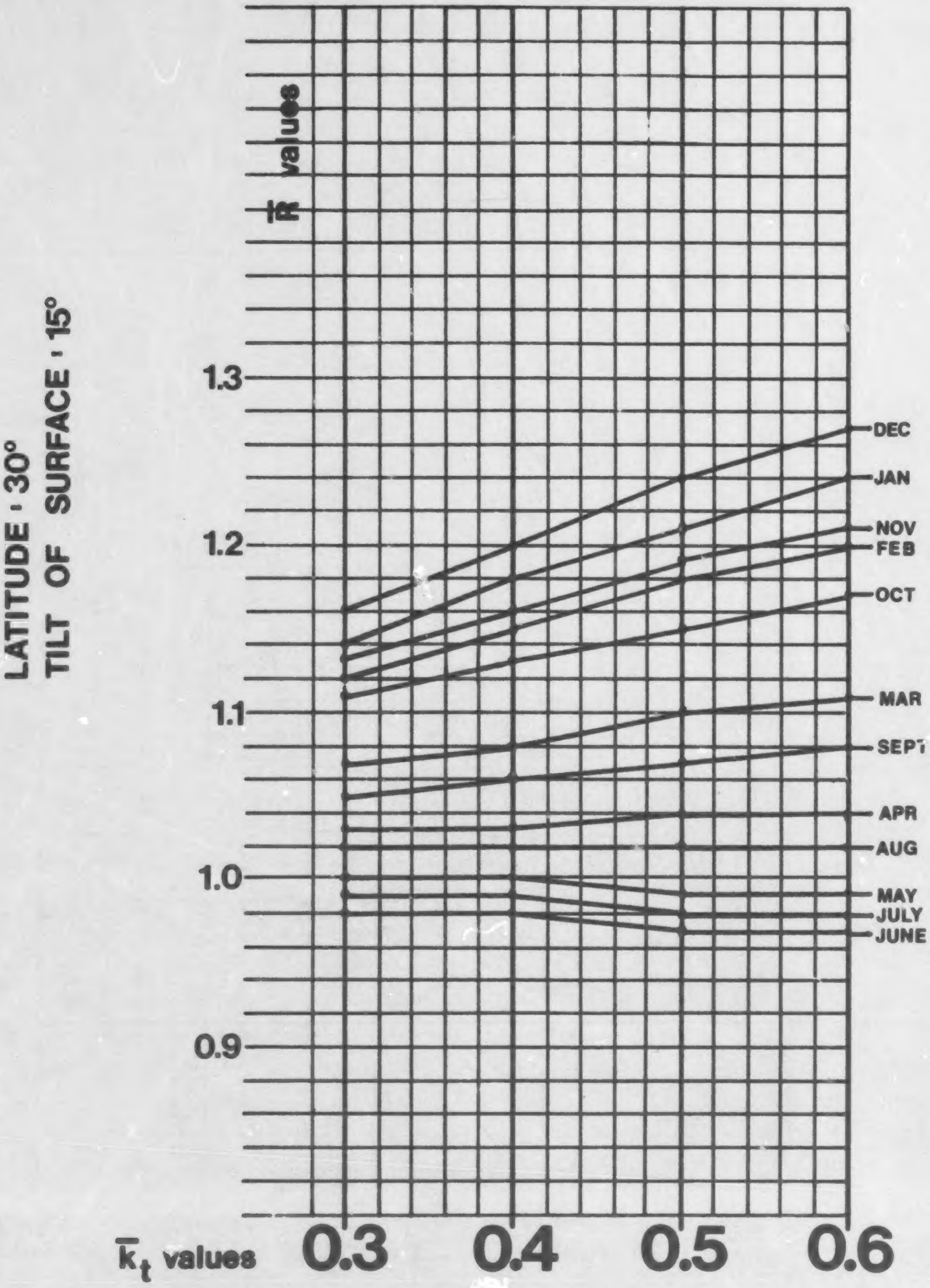
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
East Wareham, Mass.	$\bar{H}$	504.4	762.4	1132.1	1392.6	1704.8	1958.3	1873.8	1607.4	1363.8	996.7	636.2	521
Lat. 41°46′ N.	$\bar{K}_t$	0.398	0.431	0.469	0.449	0.480	0.520	0.511	0.489	0.508	0.496	0.431	0.461
El. 18 ft	t_a	22.2	31.6	39.0	48.3	58.9	67.5	74.1	72.8	65.9	56	46	34.8
Edmonton, Alberta	$\bar{H}$	231.7	652.4	1165.3	1541.7	1900.4	1914.4	1964.9	1528	1113.3	704.4	413.6	245
Lat. 53°35′ N.	$\bar{K}_t$	0.529	0.585	0.624	0.564	0.558	0.514	0.549	0.506	0.506	0.504	0.510	0.492
El. 2219 ft	t_a	10.4	14	26.3	42.9	55.4	61.3	66.6	62.2	54.2	44.1	26.7	14.0
El Paso, Texas	$\bar{H}$	1247.6	1612.9	2048.7	2447.2	2673	2731	2391.1	2350.5	2077.5	1704.8	1324.7	1051.6
Lat. 31°48′ N.	$\bar{K}_t$	0.686	0.714	0.730	0.741	0.743	0.733	0.652	0.669	0.693	0.695	0.647	0.626
El. 3916 ft	t_a	47.1	53.1	58.7	67.3	75.7	84.2	84.9	83.4	78.5	69.0	56.0	48.5
Ely, Nevada	$\bar{H}$	871.6	1255	1749.8	2103.3	2322.1	2649	2417	2307.7	1935	1473	1078.6	814.8
Lat. 39°17′ N.	$\bar{K}_t$	0.618	0.660	0.692	0.664	0.649	0.704	0.656	0.695	0.696	0.691	0.658	0.64
El. 6262 ft	t_a	27.3	32.1	39.5	48.3	57.0	65.4	74.5	72.3	63.7	52.1	39.9	31.1
Fairbanks, Alaska	$\bar{H}$	66	283.4	880.5	1481.2	1806.2	1970.8	1702.9	1247.6	899.6	323.6	104.1	20.3
Lat. 64°49′ N.	$\bar{K}_t$	0.639	0.556	0.674	0.647	0.546	0.529	0.485	0.463	0.419	0.416	0.47	0.458
El. 436 ft	t_a	−7.0	0.3	13.0	32.2	50.5	62.4	63.8	58.3	47.1	29.6	5.5	−6.6
Fort Worth, Texas	$\bar{H}$	936.2	1198.5	1597.8	1829.1	2105.1	2437.6	2293.3	2216.6	1880.8	1476	1147.6	913.6
Lat. 32°50′ N.	$\bar{K}_t$	0.530	0.541	0.577	0.556	0.585	0.654	0.624	0.653	0.634	0.612	0.576	0.563
El. 544 ft.	t_a	48.1	52.3	59.8	68.8	75.9	84.0	87.7	88.6	81.3	71.5	58.8	50.8
Fresno, Calif.	$\bar{H}$	712.9	1116.6	1652.8	2049.4	2409.2	2641.7	2512.2	2300.7	1897.8	1415.5	906.6	616.6
Lat. 36°46′ N.	$\bar{K}_t$	0.462	0.551	0.632	0.638	0.672	0.703	0.682	0.686	0.665	0.635	0.512	[illegible]
El. 331 ft.	t_a	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Gainesville, Fla.	$\bar{H}$	1036.9	1324.7	1635	1956.4	1934.7	1960.9	1895.6	1873.8	1615.1	1312.2	1169.7	919.5
Lat. 29°39′ N.	$\bar{K}_t$	0.526	0.56	0.568	0.587	0.538	0.531	0.519	0.547	0.529	0.515	0.537	0.508
El. 165 ft	t_a	62.1	63.1	67.5	72.8	79.4	83.4	83.8	84.1	82	75.7	67.2	62.4
Glasgow, Mont.	$\bar{H}$	572.7	965.7	1437.6	1741.3	2127.3	2261.6	2414.7	1984.5	1531	997	574.9	428.4
Lat. 48°13′ N.	$\bar{K}_t$	0.621	0.678	0.672	0.597	0.611	0.602	0.666	0.630	0.629	0.593	0.516	0.548
El. 2277 ft	t_a	13.3	17.3	31.1	47.8	59.3	67.3	76	73.2	61.2	49.2	31.0	18.6
Grand Junction, Colorado	$\bar{H}$	848	1210.7	1622.9	2002.2	2300.3	2645.4	2517.7	2157.2	1957.5	1394.8	969.7	793.4
Lat. 39°07′ N.	$\bar{K}_t$	0.597	0.633	0.643	0.632	0.643	0.704	0.690	0.65	0.705	0.654	0.59	0.621
El. 4849 ft	t_a	26.9	35.0	44.6	55.8	66.3	75.7	82.5	79.6	71.4	58.3	42.0	31.4
Grand Lake, Colo.	$\bar{H}$	735	1135.4	1579.3	1876.7	1974.9	2369.7	2103.3	1708.5	1715.8	1212.2	775.6	660.5
Lat. 40°15′ N.	$\bar{K}_t$	0.541	0.615	0.637	0.597	0.563	0.63	0.572	0.516	0.626	0.563	0.494	0.542
El. 8389 ft	t_a	18.5	23.1	28.5	39.1	48.7	56.6	62.8	61.5	55.5	45.2	30.3	22.6
Great Falls, Mont.	$\bar{H}$	524	869.4	1369.7	1621.4	1970.8	2179.3	2383	1986.3	1536.5	984.9	575.3	420.7
Lat. 47°29′ N.	$\bar{K}_t$	0.552	0.596	0.631	0.551	0.565	0.580	0.656	0.627	0.626	0.574	0.503	0.518
El. 3664 ft	t_a	25.4	27.6	35.6	47.7	57.5	64.3	73.8	71.3	60.6	51.4	38.0	29.1
Greensboro, N. C.	$\bar{H}$	743.9	1031.7	1323.2	1755.3	1988.5	2111.4	2033.9	1810.3	1517.3	1202.6	908.1	690.8
Lat. 36°05′ N.	$\bar{K}_t$	0.469	0.499	0.499	0.543	0.554	0.563	0.552	0.538	0.527	0.531	0.501	0.479
El. 891 ft	t_a	42.0	44.2	51.7	60.8	69.9	78.0	80.2	78.9	73.9	62.7	51.5	43.2
Griffin, Georgia	$\bar{H}$	889.6	1135.8	1450.9	1923.6	2163.1	2176	2064.9	1961.2	1605.9	1352.4	1073.8	781.5
Lat. 33°15′ N.	$\bar{K}_t$	0.513	0.517	0.528	0.586	0.601	0.583	0.562	0.578	0.543	0.565	0.545	0.467
El. 980 ft	t_a	48.9	51.0	59.1	66.7	74.6	81.2	83.0	82.2	78.4	68	57.3	49.4
Hatteras, N. C.	$\bar{H}$	891.9	1184.1	1590.4	2128	2376.4	2438	2334.3	2085.6	1758.3	1337.6	1053.5	798.1
Lat. 35°13′ N.	$\bar{K}_t$	0.546	0.563	0.593	0.655	0.661	0.652	0.634	0.619	0.605	0.58	0.566	0.535
El. 7 ft	t_a	49.9	49.5	54.7	61.3	69.9	77.2	80.0	79.8	76.7	67.9	59.1	51.3
Indianapolis, Ind.	$\bar{H}$	526.2	797.4	1184.1	1481.2	1828	2042	2039.5	1832.1	1513.3	1094.4	662.4	491.1
Lat. 39°44′ N.	$\bar{K}_t$	0.380	0.424	0.472	0.47	0.511	0.543	0.554	0.552	0.549	0.520	0.413	0.391
El. 793 ft	t_a	31.3	33.9	43.0	54.1	64.9	74.8	79.6	77.4	70.6	59.3	44.2	33.4
Inyokern, Calif.	$\bar{H}$	1148.7	1554.2	2136.9	2594.8	2925.4	3108.8	2908.8	2759.4	2409.2	1819.2	1370,1	1094.4
Lat. 35°39′ N.	$\bar{K}_t$	0.716	0.745	0.803	0.8	0.815	0.830	0.790	0.820	0.834	0.795	0.743	0.742
El. 2440 ft	t_a	47.3	53.9	59.1	65.6	73.5	80.7	87.5	84.9	78.6	68.7	57.3	48.9
Ithaca, N. Y.	$\bar{H}$	434.3	735	1074.9	1322.9	1779.3	2025.8	2031.3	1736.9	1320.3	918.4	466.4	370.8
Lat. 42°27′ N.	$\bar{K}_t$	0.351	0.435	0.45	0.428	0.502	0.538	0.554	0.530	0.497	0.465	0.324	0.337
El. 950 ft	t_a	27.2	28.5	38	48.4	59.6	68.9	73.9	71.9	64.2	53.6	41.5	29.6
Lake Charles, La.	$\bar{H}$	899.2	1145.7	1487.4	1801.8	2080.4	2213.3	1968.6	1910.3	1678.2	1505.5	1122.1	875.6
Lat. 30°13′ N.	$\bar{K}_t$	0.473	0.492	0.521	0.542	0.578	0.597	0.538	0.558	0.553	0.597	0.524	0.494
El. 12 ft	t_a	55.3	58.7	63.5	70.9	77.4	83.4	84.8	85.0	81.5	73.8	62.6	56.9
Lander, Wyo.	$\bar{H}$	788.3	1146.1	1638	1988.5	2114	2492.2	2438.4	2120.6	1712.9	1301.8	837.3	694.8
Lat. 42°48′ N.	$\bar{K}_t$	0.65	0.672	0.691	0.647	0.587	0.662	0.665	0.649	0.647	0.666	0.589	0.643
El. 5370 ft	t_a	20.2	26.3	34.7	45.5	56.0	65.4	74.6	72.5	61.4	48.3	33.4	23.8

		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Las Vegas, Nev.	$\bar{H}$	1035.8	1438	1926.5	2322.8	2629.5	2799.2	2524	2342	2062	1602.6	1190	964.2
Lat. 36°05′ N.	$\bar{K}_t$	0.654	0.697	0.728	0.719	0.732	0.746	0.685	0.697	0.716	0.704	0.657	0.668
El. 2162 ft	t_a	47.5	53.9	60.3	69.5	78.3	88.2	95.0	92.9	85.4	71.7	57.8	50.2
Lemont, Illinois	$\bar{H}$	(590)	879	1255.7	1481.5	1866	2041.7	1990.8	1836.9	1469.4	1015.5	(639)	(531)
Lat. 41°40′ N.	$\bar{K}_t$	(0.464)	0.496	0.520	0.477	0.525	0.542	0.542	0.559	0.547	0.506	(0.433)	(0.467
El. 595 ft	t_a	28.9	30.3	39.5	49.7	59.2	70.8	75.6	74.3	67.2	57.6	43.0	30.6
Lexington, Ky.	$\bar{H}$	—	—	—	1834.7	2171.2	—	2246.5	2064.9	1775.6	1315.8	—	681.5
Lat. 38°02′ N.	$\bar{K}_t$	—	—	—	0.575	0.606	—	0.610	0.619	0.631	0.604	—	0.513
El. 979 ft	t_a	36.5	38.8	47.4	57.8	67.5	76.2	79.8	78.2	72.8	61.2	47.6	38.5
Lincoln, Neb.	$\bar{H}$	712.5	955.7	1299.6	1587.8	1856.1	2040.6	2011.4	1902.6	1543.5	1215.8	773.4	643.2
Lat. 40°51′ N.	$\bar{K}_t$	0.542	0.528	0.532	0.507	0.522	0.542	0.547	0.577	0.568	0.596	0.508	0.545
El. 1189 ft	t_a	27.8	32.1	42.4	55.8	65.8	76.0	82.6	80.2	71.5	59.9	43.2	31.8
Little Rock, Ark.	$\bar{H}$	704.4	974.2	1335.8	1669.4	1960.1	2091.5	2081.2	1938.7	1640.6	1282.6	913.6	701.1
Lat. 34°44′ N.	$\bar{K}_t$	0.424	0.458	0.496	0.513	0.545	0.559	0.566	0.574	0.561	0.552	0.484	0.463
El. 265 ft	t_a	44.6	48.5	56.0	65.8	73.1	76.7	85.1	84.6	78.3	67.9	54.7	46.7
Los Angeles, Calif. (WBAS)	$\bar{H}$	930.6	1284.1	1729.5	1948	2196.7	2272.3	2413.6	2155.3	1898.1	1372.7	1082.3	901.1
Lat. 33°56′ N.	$\bar{K}_t$	0.547	0.596	0.635	0.596	0.610	0.608	0.657	0.635	0.641	0.574	0.551	0.566
El. 99	t_a	56.2	56.9	59.2	61.4	64.2	66.7	69.6	70.2	69.1	66.1	62.6	58.7
Los Angeles, Calif. (WBO)	$\bar{H}$	911.8	1223.6	1640.9	1866.8	2061.2	2250	2428.4	2198.9	1891.5	1362.3	1053.1	877.8
Lat. 34°03′ N.	$\bar{K}_t$	0.538	0.568	0.602	0.571	0.573	0.606	0.66	0.648	0.643	0.578	0.548	0.566
	t_a	57.9	59.2	61.8	64.3	67.6	70.7	75.8	76.1	74.2	69.6	65.4	60.2
Madison, Wis.	$\bar{H}$	564.6	812.2	1232.1	1455.3	1745.4	2031.7	2046.5	1740.2	1443.9	993	555.7	495.9
Lat. 43°08′ N.	$\bar{K}_t$	0.49	0.478	0.522	0.474	0.493	0.540	0.559	0.534	0.549	0.510	0.396	0.467
El. 866 ft	t_a	21.8	24.6	35.3	49.0	61.0	70.9	76.8	74.4	65.6	53.7	37.8	25.4
Matanuska, Alaska	$\bar{H}$	119.2	345	—	1327.6	1628.4	1727.6	1526.9	1169	737.3	373.8	142.8	56.4
Lat. 61°30′ N.	$\bar{K}_t$	0.513	0.503	—	0.545	0.494	0.466	0.434	0.419	0.401	0.390	0.372	0.364
El. 180 ft	t_a	13.9	21.0	27.4	38.6	50.3	57.6	60.1	58.1	50.2	37.7	22.9	13.9
Medford, Oregon	$\bar{H}$	435.4	804.4	1259.8	1807.4	2216.2	2440.5	2607.4	2261.6	1672.3	1043.5	558.7	346.5
Lat. 42°23′ N.	$\bar{K}_t$	0.353	0.464	0.527	0.584	0.625	0.648	0.710	0.689	0.628	0.526	0.384	0.313
El. 1329 ft	t_a	39.4	45.4	50.8	56.3	63.1	69.4	76.9	76.4	69.6	58.7	47.1	40.5
Miami, Florida	$\bar{H}$	1292.2	1554.6	1828.8	2020.6	2068.6	1991.5	1992.6	1890.8	1646.8	1436.5	1321	1183.4
Lat. 25°47′ N.	$\bar{K}_t$	0.604	0.616	0.612	0.600	0.578	0.545	0.552	0.549	0.525	0.534	0.559	0.558
El. 9 ft	t_a	71.6	72.0	73.8	77.0	79.9	82.9	84.1	84.5	83.3	80.2	75.6	72.6
Midland, Texas	$\bar{H}$	1066.4	1345.7	1784.8	2036.1	2301.1	2317.7	2301.8	2193	1921.8	1470.8	1244.3	1023.2
Lat. 31°56′ N.	$\bar{K}_t$	0.587	0.596	0.638	0.617	0.639	0.622	0.628	0.643	0.642	0.600	0.609	0.611
El. 2854 ft	t_a	47.9	52.8	60.0	68.8	77.2	83.9	85.7	85.0	78.9	70.3	56.6	49.1
Nashville, Tenn.	$\bar{H}$	589.7	907	1246.8	1662.3	1997	2149.4	2079.7	1862.7	1600.7	1223.6	823.2	614.4
Lat. 36°07′ N.	$\bar{K}_t$	0.373	0.440	0.472	0.514	0.556	0.573	0.565	0.554	0.556	0.540	0.454	0.426
El. 605 ft	t_a	42.6	45.1	52.9	63.0	71.4	80.1	83.2	81.9	76.6	65.4	52.3	44.3
Newport, R. I.	$\bar{H}$	565.7	856.4	1231.7	1484.8	1849	2019.2	1942.8	1687.1	1411.4	1035.4	656.1	527.7
Lat. 41°29′ N.	$\bar{K}_t$	0.438	0.482	0.507	0.477	0.520	0.536	0.529	0.513	0.524	0.512	0.44	0.460
El. 60 ft	t_a	29.5	32.0	39.6	48.2	58.6	67.0	73.2	72.3	66.7	56.2	46.5	34.4
New York, N. Y.	$\bar{H}$	539.5	790.8	1180.4	1426.2	1738.4	1994.1	1938.7	1605.9	1349.4	977.8	598.1	476
Lat. 40°46′ N.	$\bar{K}_t$	0.406	0.435	0.480	0.455	0.488	0.53	0.528	0.486	0.500	0.475	0.397	0.403
El. 52 ft	t_a	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Oak Ridge, Tenn.	$\bar{H}$	604	895.9	1241.7	1689.6	1942.8	2066.4	1972.3	1795.6	1559.8	1194.8	796.3	610
Lat. 36°01′ N.	$\bar{K}_t$	0.382	0.435	0.471	0.524	0.541	0.551	0.536	0.534	0.542	0.527	0.438	0.422
El. 905 ft	t_a	41.9	44.2	51.7	61.4	69.8	77.8	80.2	78.8	74.5	62.7	50.4	42.5
Oklahoma City, Oklahoma	$\bar{H}$	938	1192.6	1534.3	1849.4	2005.1	2355	2273.8	2211	1819.2	1409.6	1085.6	897.4
Lat. 35°24′ N.	$\bar{K}_t$	0.580	0.571	0.576	0.570	0.558	0.629	0.618	0.656	0.628	0.614	0.588	0.608
El. 1304 ft	t_a	40.1	45.0	53.2	63.6	71.2	80.6	85.5	85.4	77.4	66.5	52.2	43.1
Ottawa, Ontario	$\bar{H}$	539.1	852.4	1250.5	1506.6	1857.2	2084.5	2045.4	1752.4	1326.6	826.9	458.7	406.5
Lat. 45°20′ N.	$\bar{K}_t$	0.499	0.540	0.554	0.502	0.529	0.554	0.560	0.546	0.521	0.450	0.359	0.436
El. 339 ft	t_a	14.6	15.6	27.7	43.3	57.5	67.5	71.9	69.8	61.5	48.9	35	19.6
Phoenix, Ariz.	$\bar{H}$	1126.6	1514.7	1967.1	2388.2	2709.6	2781.5	2450.5	2299.6	2131.3	1688.9	1290	1040.9
Lat. 33°26′ N.	$\bar{K}_t$	0.65	0.691	0.716	0.728	0.753	0.745	0.667	0.677	0.722	0.708	0.657	0.652
El. 1112 ft	t_a	54.2	58.8	64.7	72.2	80.8	89.2	94.6	92.5	87.4	75.8	63.6	56.7
Portland, Maine	$\bar{H}$	565.7	874.5	1329.5	1528.4	1923.2	2017.3	2095.6	1799.2	1428.8	1035	591.5	507.7
Lat. 43°39′ N.	$\bar{K}_t$	0.482	0.524	0.569	0.500	0.544	0.536	0.572	0.554	0.546	0.539	0.431	0.491
El. 63 ft	t_a	23.7	24.5	34.4	44.8	55.4	65.1	71.1	69.7	61.9	51.8	40.3	28.0

		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rapid City, S. D.	$\bar{H}$	687.8	1032.5	1503.7	1807	2028	2193.7	2235.8	2019.9	1625	1179.3	763.1	590.4
Lat. 44°09′ N.	$\bar{K}_t$	0.601	0.627	0.649	0.594	0.574	0.583	0.612	0.622	0.628	0.624	0.566	0.588
El. 3218 ft	t_a	24.7	27.4	34.7	48.2	58.3	67.3	76.3	75.0	64.7	52.9	38.7	29.2
Riverside, Calif.	$\bar{H}$	999.6	1335	1750.5	1943.2	2282.3	2492.6	2443.5	2263.8	1955.3	1509.6	1169	979.7
Lat. 33°57′ N.	$\bar{K}_t$	0.580	0.617	0.643	0.594	0.635	0.667	0.665	0.668	0.665	0.639	0.606	0.626
El. 1020 ft	t_a	56.3	57.0	60.6	65.0	69.4	74.0	81.0	81.0	78.5	71.0	63.1	57.2
Saint Cloud, Minn.	$\bar{H}$	632.8	976.7	1383	1598.1	1859.4	2003.3	2087.8	1828.4	1369.4	890.4	545.4	463.1
Lat. 45°35′ N.	$\bar{K}_t$	0.595	0.629	0.614	0.534	0.530	0.533	0.573	0.570	0.539	0.490	0.435	0.504
El. 1034 ft	t_a	13.6	16.9	29.8	46.2	58.8	68.5	74.4	71.9	62.5	50.2	32.1	18.3
Salt Lake City, Utah	$\bar{H}$	622.1	986	1301.1	1813.3	—	—	—	—	1689.3	1250.2	—	552.8
Lat. 40°46′ N.	$\bar{K}_t$	0.468	0.909	0.529	0.578	—	—	—	—	0.621	0.610	—	0.467
El. 4227 ft	t_a	29.4	36.2	44.4	53.9	63.1	71.7	81.3	79.0	68.7	57.0	42.5	34.0
San Antonio, Tex.	$\bar{H}$	1045	1299.2	1560.1	1664.6	2024.7	814.8	2364.2	2185.2	1844.6	1487.4	1104.4	954.8
Lat. 29°32′ N.	$\bar{K}_t$	0.541	0.550	0.542	0.500	0.563	0.220	0.647	0.637	0.603	0.584	0.507	0.528
El. 794 ft	t_a	53.7	58.4	65.0	72.2	79.2	85.0	87.4	87.8	82.6	74.7	63.3	56.5
Santa Maria, Calif.	$\bar{H}$	983.8	1296.3	1805.9	2067.9	2375.6	2599.6	2540.6	2293.3	1965.7	1566.4	1169	943.9
Lat. 34°54′ N.	$\bar{K}_t$	0.595	0.613	0.671	0.636	0.661	0.695	0.690	0.678	0.674	0.676	0.624	0.627
El. 238 ft	t_a	54.1	55.3	57.6	59.5	61.2	63.5	65.3	65.7	65.9	64.1	60.8	56.1
Sault Ste. Marie, Michigan	$\bar{H}$	488.6	843.9	1336.5	1559.4	1962.3	2064.2	2149.4	1767.9	1207	809.2	392.2	359.8
Lat. 46°28′ N.	$\bar{K}_t$	0.490	0.560	0.606	0.526	0.560	0.549	0.590	0.554	0.481	0.457	0.323	0.408
El. 724 ft	t_a	16.3	16.2	25.6	39.5	52.1	61.6	67.3	66.0	57.9	46.8	33.4	21.9
Sayville, N. Y.	$\bar{H}$	602.9	936.2	1259.4	1500.5	1857.2	2123.2	2040.9	1734.7	1446.8	1067.4	697.8	533.9
Lat. 40°30′ N.	$\bar{K}_t$	0.453	0.511	0.510	0.498	0.522	0.564	0.555	0.525	0.530	0.527	0.450	0.447
El. 20 ft	t_a	35	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Schenectady, N. Y.	$\bar{H}$	488.2	753.5	1026.6	1272.3	1553.1	1687.8	1662.3	1494.8	1124.7	820.6	436.2	356.8
Lat. 42°50′ N.	$\bar{K}_t$	0.406	0.441	0.433	0.413	0.438	0.448	0.454	0.458	0.426	0.420	0.309	0.331
El. 217 ft	t_a	24.7	24.6	34.9	48.3	61.7	70.8	76.9	73.7	64.6	53.1	40.1	28.0
Seattle, Wash.	$\bar{H}$	282.6	520.6	992.2	1507	1851.5	1909.9	2110.7	1688.5	1211.8	702.2	386.3	239.5
Lat. 47°27′ N.	$\bar{K}_t$	0.296	0.355	0.456	0.510	0.538	0.506	0.581	0.533	0.492	0.407	0.336	0.292
El. 386 ft	t_a	42.1	45.0	48.9	54.1	59.8	64.4	68.4	67.9	63.3	56.3	48.4	44.4
Seattle, Wash.	$\bar{H}$	252	471.6	917.3	1375.6	1664.9	1724	1805.1	1617	1129.1	638	325.5	218.1
Lat. 47°36′ N.	$\bar{K}_t$	0.266	0.324	0.423	0.468	0.477	0.459	0.498	0.511	0.459	0.372	0.284	0.269
El. 14 ft	t_a	38.9	42.9	46.9	51.9	58.1	62.8	67.2	66.7	61.6	54.0	45.7	41.5
Seabrook, N. J.	$\bar{H}$	501.9	854.2	1195.6	1518.8	1800.7	1964.6	1949.8	1715	1445.7	1071.9	721.8	522.5
Lat. 39°30′ N.	$\bar{K}_t$	0.426	0.453	0.476	0.481	0.504	0.522	0.530	0.517	0.524	0.508	0.449	0.416
El. 100 ft	t_a	39.5	37.6	43.9	54.7	64.9	74.1	79.8	77.7	69.7	61.2	48.5	39.3
Spokane, Wash.	$\bar{H}$	446.1	837.6	1200	1764.0	2104.4	2226.5	2479.7	2076	1511	844.6	486.3	279
Lat. 47°40′ N.	$\bar{K}_t$	0.478	0.579	0.556	0.602	0.603	0.593	0.684	0.656	0.616	0.494	0.428	0.345
El. 1968	t_a	28.5	31.7	40.5	49.2	57.9	64.6	73.4	71.7	62.7	51.5	37.4	30.3
State College, Pa.	$\bar{H}$	501.8	749.1	1106.6	1399.2	1754.6	2027.6	1908.2	1690	1336.1	1017	580.1	443.9
Lat. 40°48′ N.	$\bar{K}_t$	0.381	0.413	0.451	0.448	0.493	0.539	0.536	0.512	0.492	0.496	0.379	0.376
El. 1175 ft	t_a	31.3	31.4	39.8	51.3	63.4	71.8	75.8	73.4	66.1	55.6	43.2	32.6
Stillwater, Okla.	$\bar{H}$	763.8	1081.5	1463.8	1702.6	1879.3	2235.8	2224.3	2039.1	1724.3	1314	991.5	783
Lat. 36°09′ N.	$\bar{K}_t$	0.484	0.527	0.355	0.528	0.523	0.596	0.604	0.607	0.599	0.581	0.548	0.544
El. 910 ft	t_a	41.2	45.6	53.8	64.2	71.6	81.1	85.9	85.9	77.5	67.6	52.6	43.9
Tampa, Fla.	$\bar{H}$	1223.6	1461.2	1771.9	2016.2	2228	2146.5	1991.9	1845.4	1657.8	1493.3	1328.4	1119.5
Lat. 27°55′ N.	$\bar{K}_t$	0.605	0.600	0.606	0.602	0.620	0.583	0.548	0.537	0.546	0.572	0.390	0.580
El. 11 ft	t_a	64.2	65.7	68.8	74.3	79.4	83.0	84.0	84.4	82.9	77.2	69.6	65.5
Toronto, Ontario	$\bar{H}$	451.3	674.5	1088.9	1388.2	1785.2	1941.7	1968.6	1622.5	1284.1	835	458.3	352.8
Lat. 43°41′ N.	$\bar{K}_t$	0.388	0.406	0.467	0.455	0.506	0.516	0.539	0.500	0.493	0.438	0.336	0.346
El. 379 ft	t_a	26.5	26.0	34.2	46.3	58	68.4	73.8	71.8	64.3	52.6	40.9	30.2
Tucson, Arizona	$\bar{H}$	1171.9	1453.8	—	2434.7	—	2601.4	2292.2	2175.7	2122.5	1640.9	1322.1	1132.1
Lat. 32°07′ N.	$\bar{K}_t$	0.648	0.646	—	0.738	—	0.698	0.625	0.640	0.710	0.672	0.650	0.679
El. 2556 ft	t_a	53.7	57.3	62.3	69.7	78.0	87.0	90.1	87.4	84.0	73.9	62.5	56.1
Upton, N. Y.	$\bar{H}$	583	872.7	1230.4	1609.9	1891.5	2159	2044.6	1789.6	1472.7	1102.6	686.7	551.3
Lat. 40°52′ N.	$\bar{K}_t$	0.444	0.483	0.522	0.514	0.532	0.574	0.557	0.542	0.542	0.538	0.448	0.467
El. 75 ft	t_a	35.0	34.9	43.1	52.3	63.3	72.2	76.9	75.3	69.5	59.3	48.3	37.7
Washington, D. C. (WBCO)	$\bar{H}$	632.4	901.5	1255	1600.4	1846.8	2080.8	1929.9	1712.2	1446.1	1083.4	763.5	594.1
Lat. 38°51′ N.	$\bar{K}_t$	0.443	0.470	0.496	0.504	0.516	0.553	0.524	0.516	0.520	0.506	0.464	0.460
El. 64 ft	t_a	38.4	39.6	46.1	57.5	67.7	76.2	79.9	77.9	72.2	60.9	50.2	40.2
Winnipeg, Man.	$\bar{H}$	488.2	835.4	1354.2	1641.3	1904.4	1962	2123.6	1761.2	1190.4	767.5	444.6	345
Lat. 49°54′ N.	$\bar{K}_t$	0.601	0.636	0.661	0.574	0.530	0.524	0.557	0.567	0.504	0.452	0.436	0.503
El. 786 ft	t_a	3.2	7.1	21.3	40.9	55.9	65.3	71.9	69.4	56.6	45.6	25.2	10.1

solar data for inclined surfaces

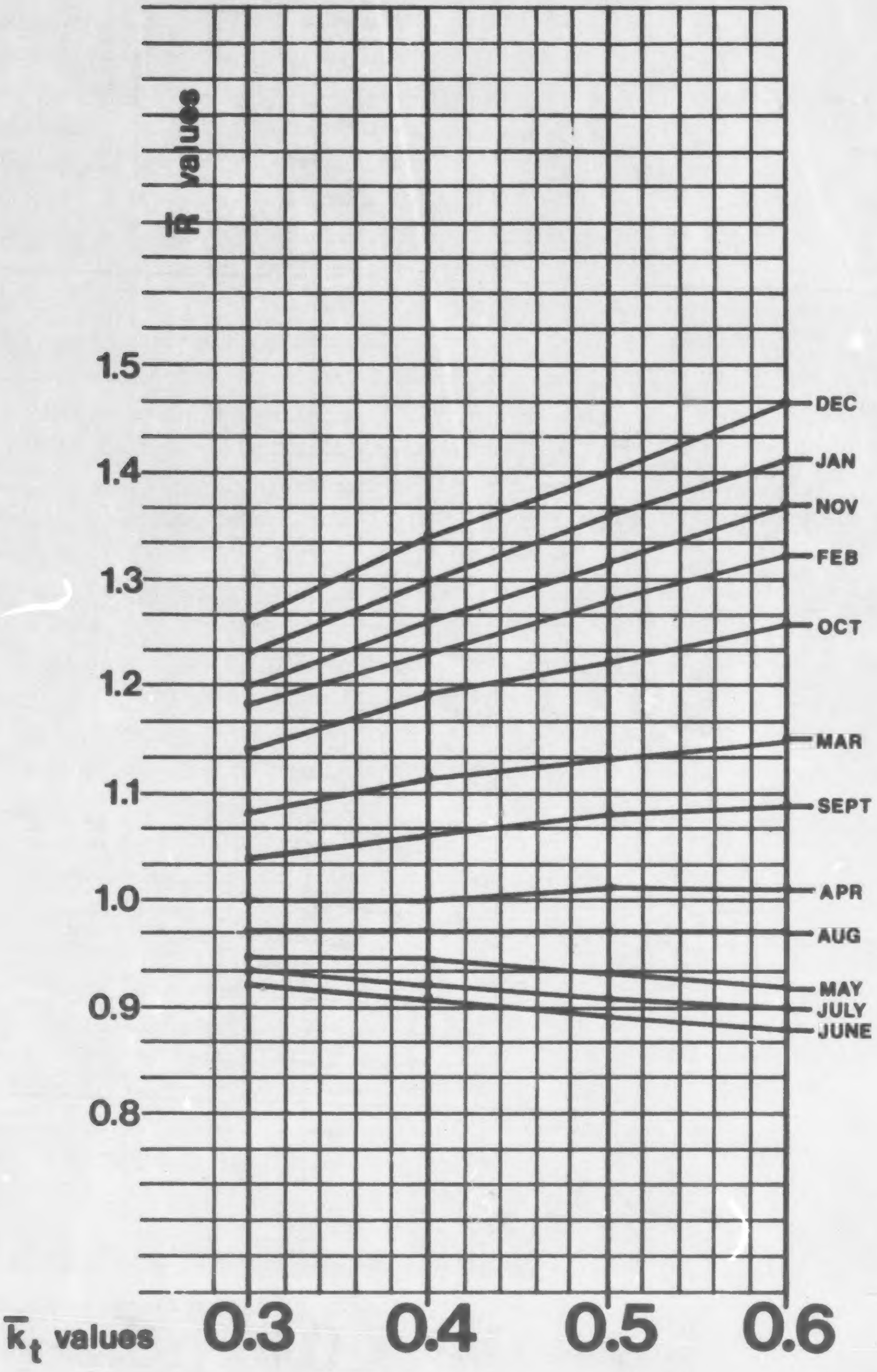
conversion of $\overline{K}_t$ to $\overline{R}$



66/67

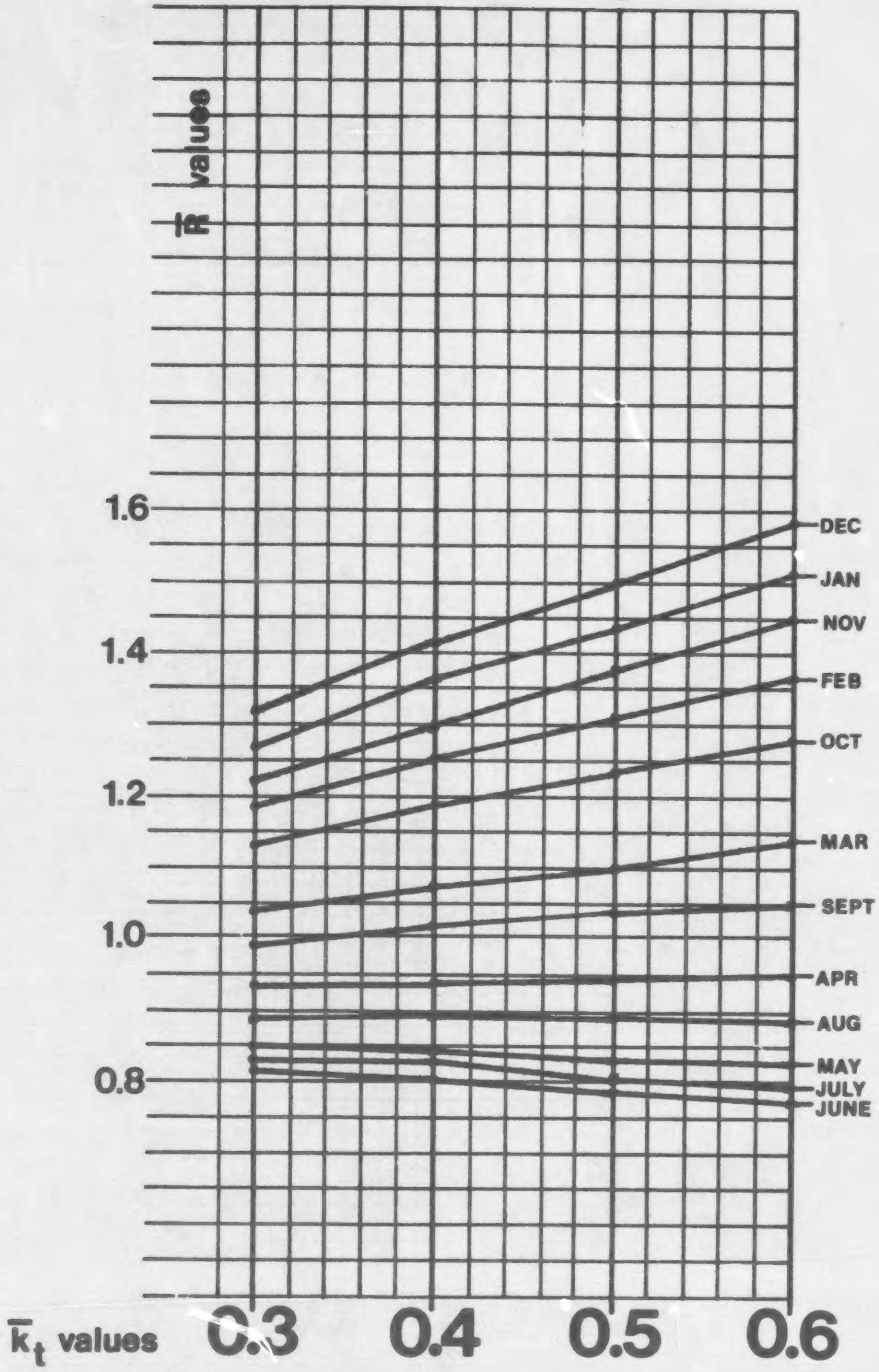
conversion of $\overline{K}_t$ to $\overline{R}$

LATITUDE ·30°
TILT OF SURFACE ·30°

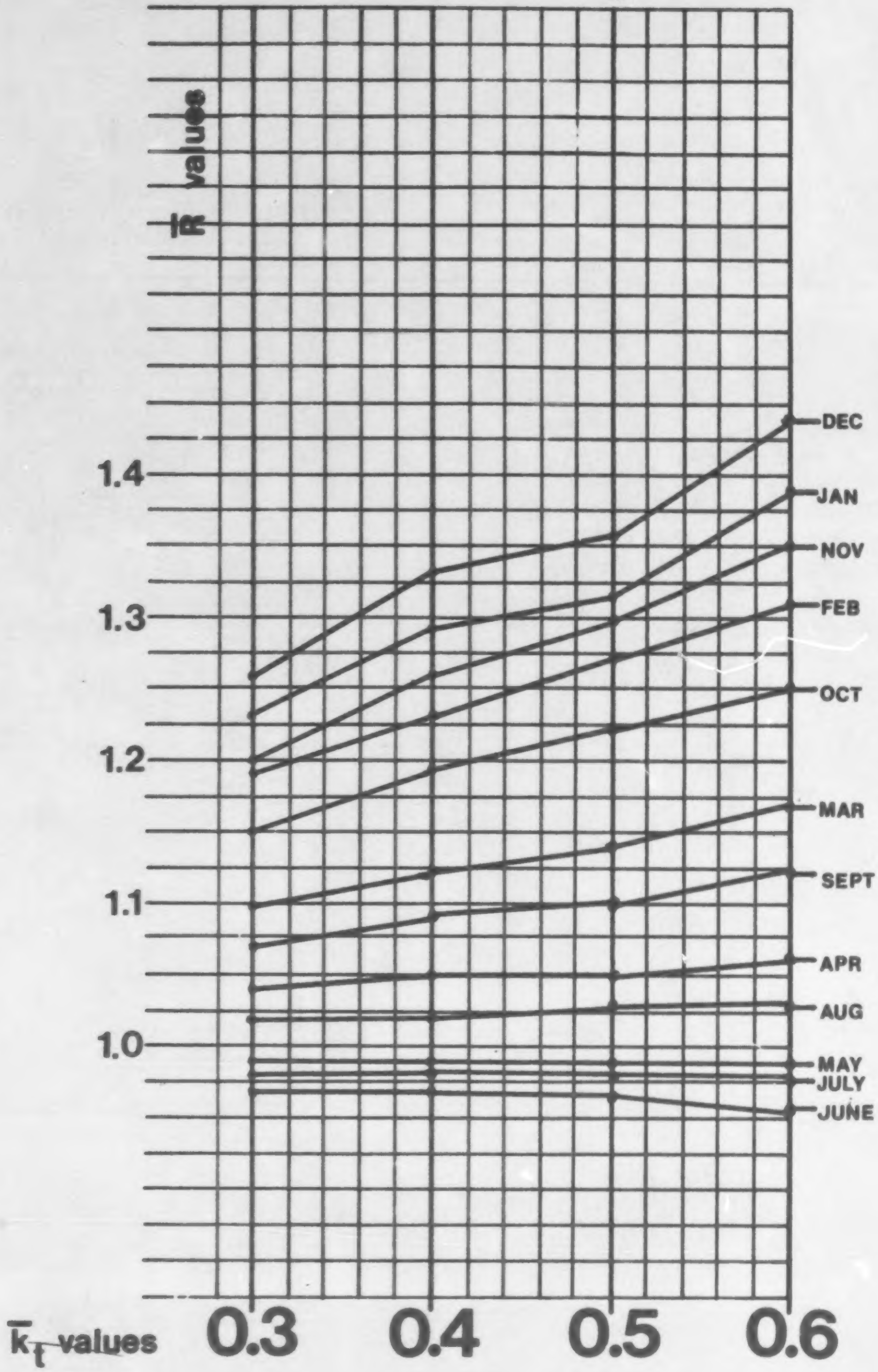


conversion of $\overline{K}_t$ to $\overline{R}$

LATITUDE ·30°
TILT OF SURFACE ·45°



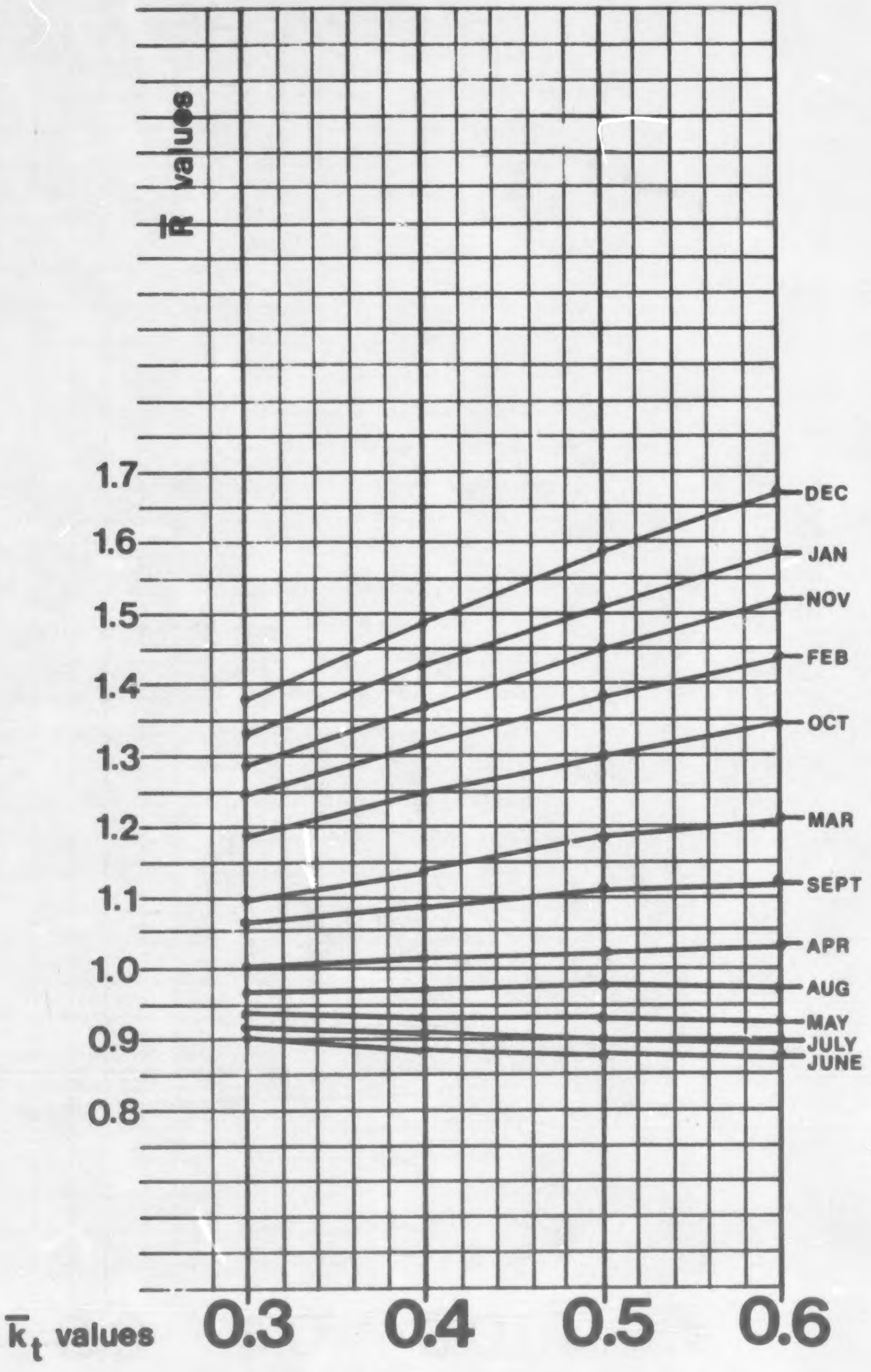
conversion of $\overline{K}_t$ to $\overline{R}$



LATITUDE · 35°
TILT OF SURFACE · 20°

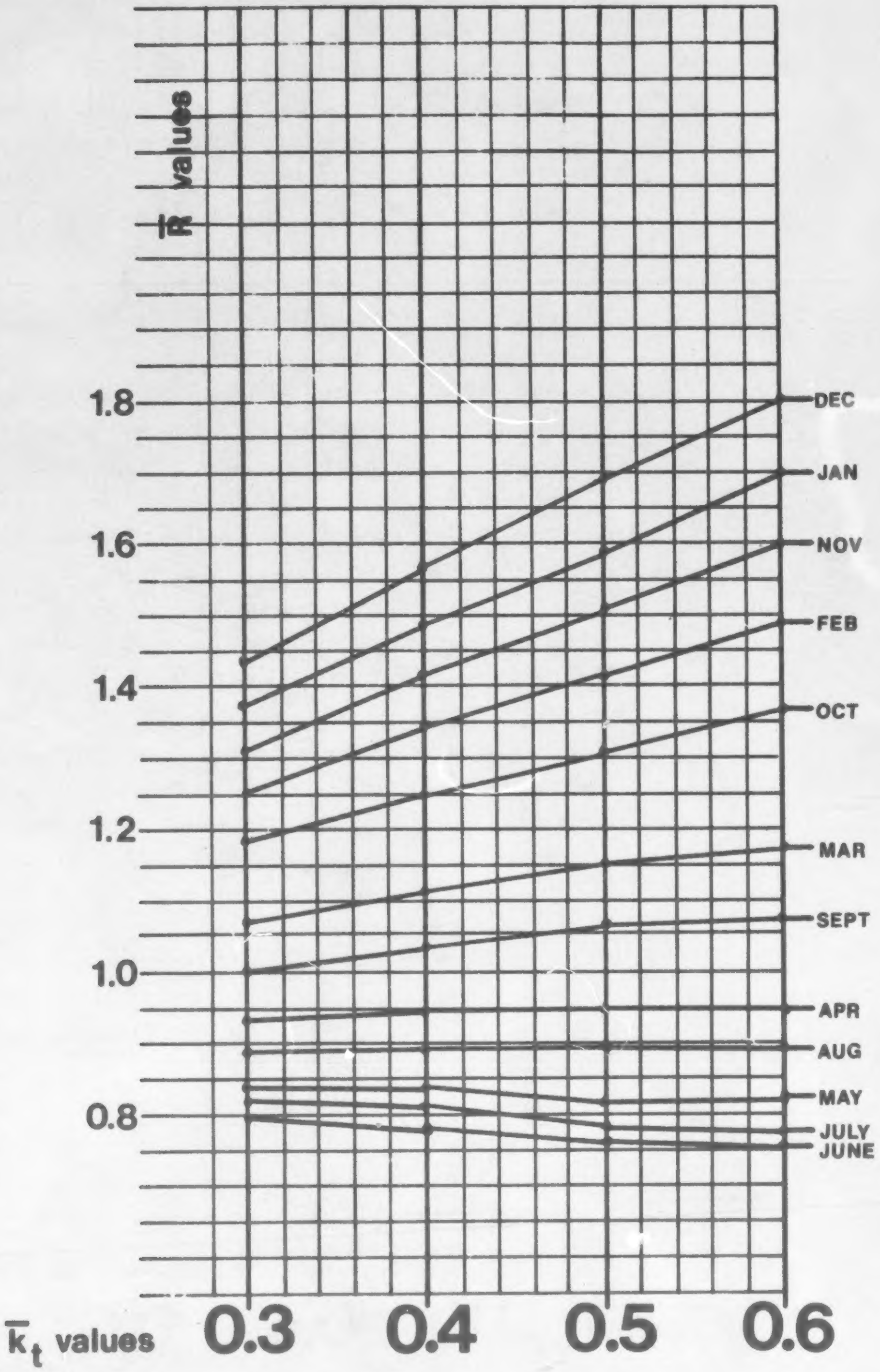
conversion of $\overline{K}_t$ to $\overline{R}$

LATITUDE ·35°
TILT OF SURFACE ·35°



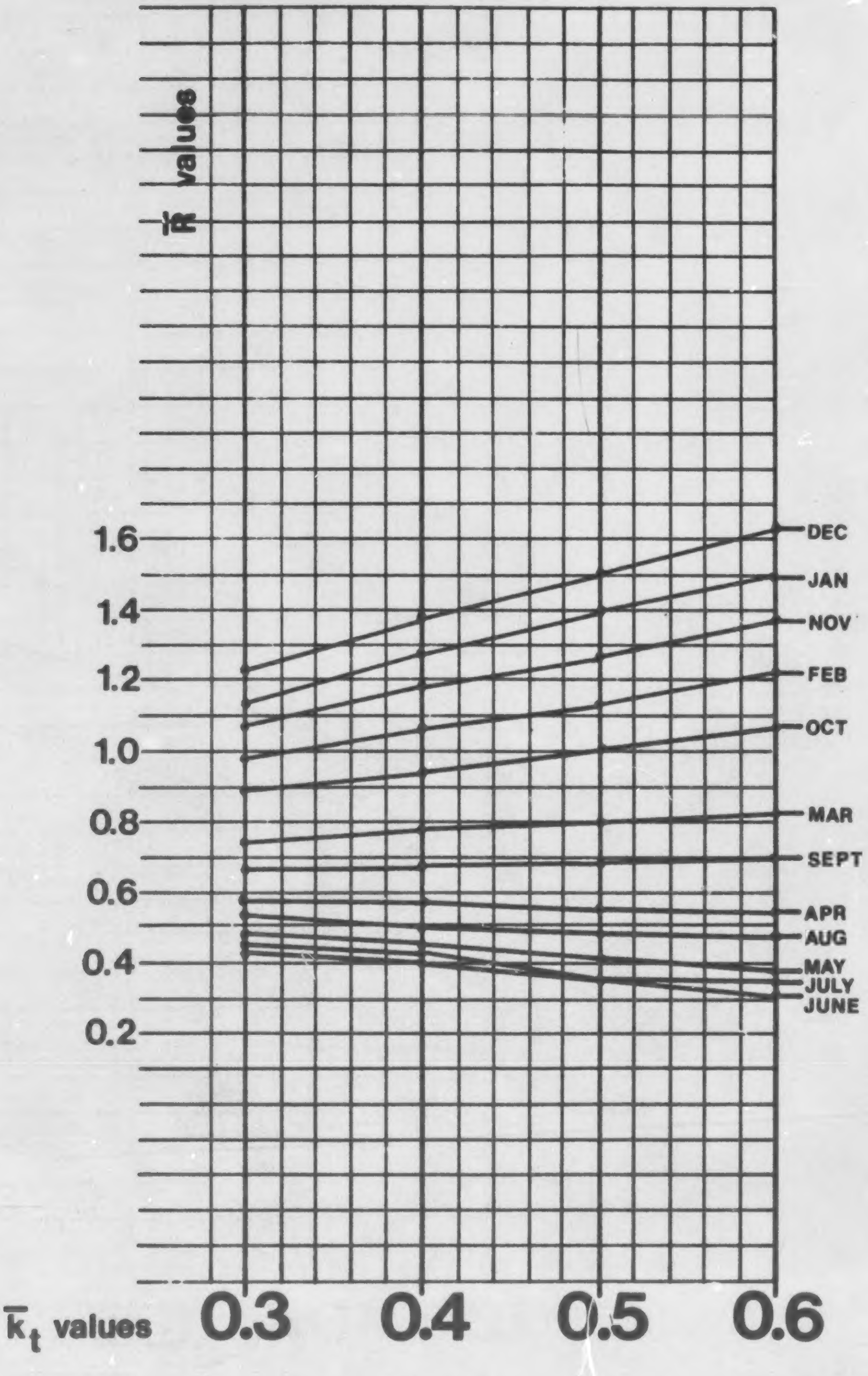
conversion of $\overline{K}_t$ to $\overline{R}$

LATITUDE : 35°
TILT OF SURFACE : 50°

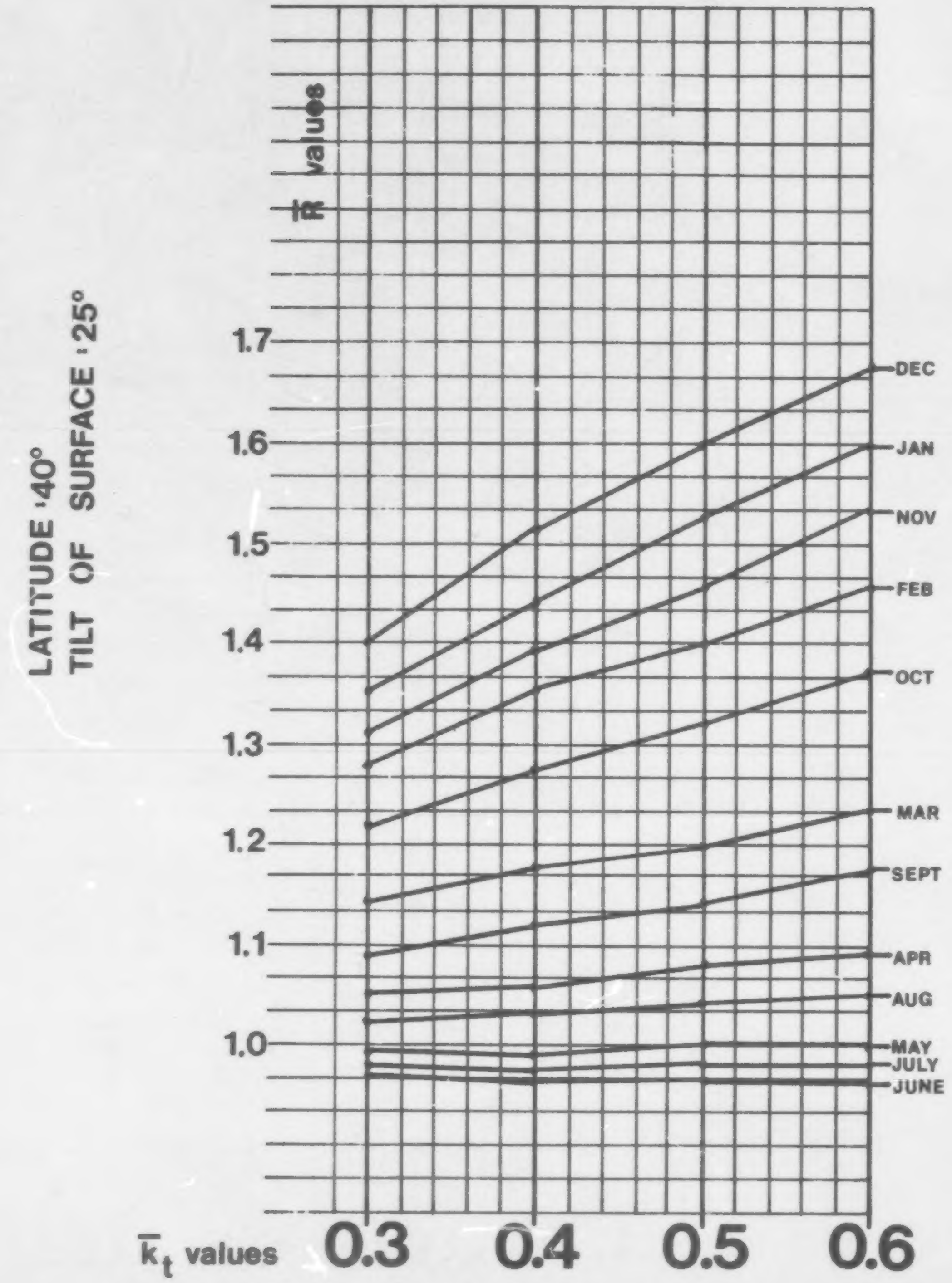


conversion of $\overline{K}_t$ to $\overline{R}$

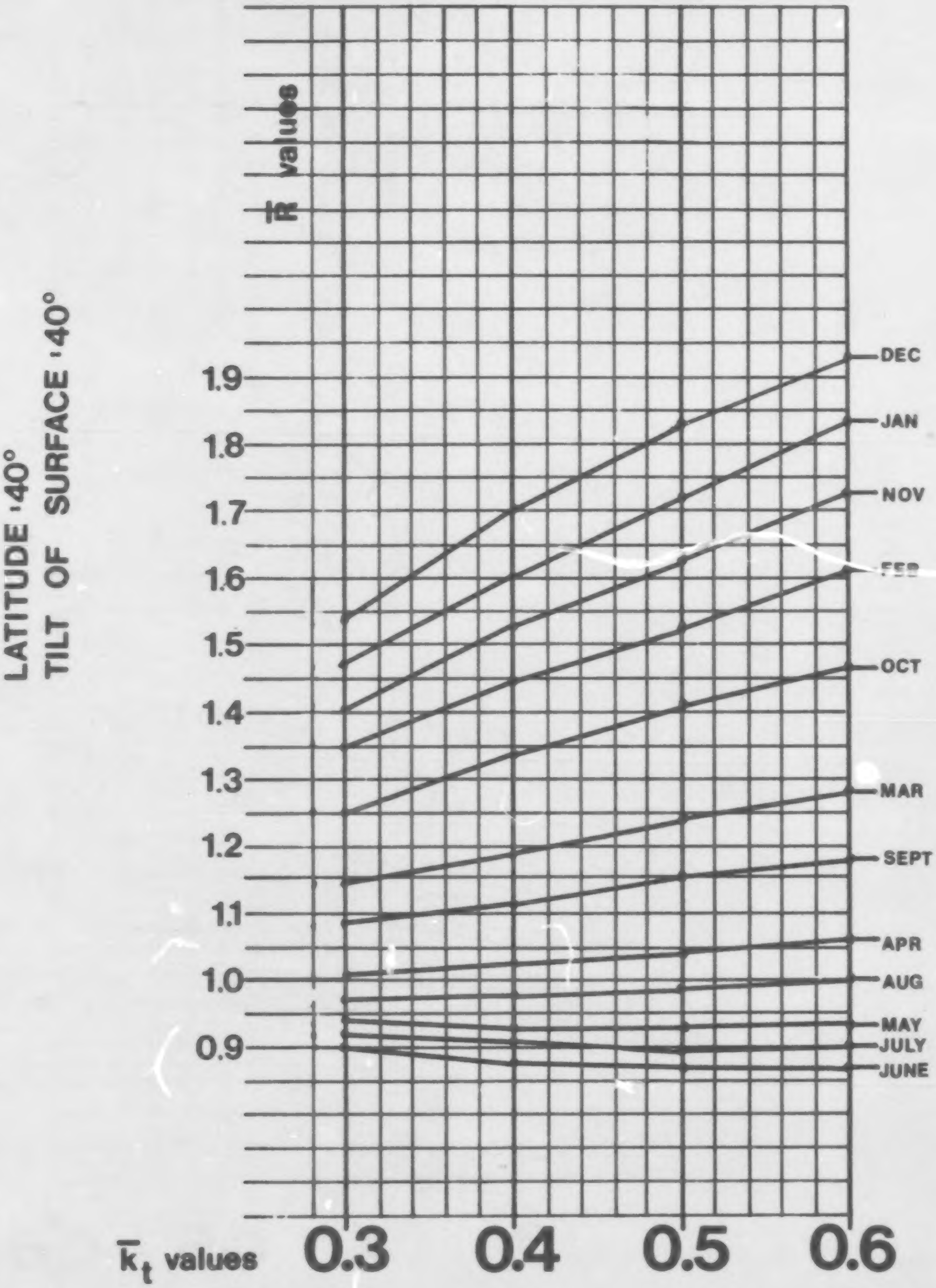
LATITUDE ·35°
TILT OF SURFACE ·90°



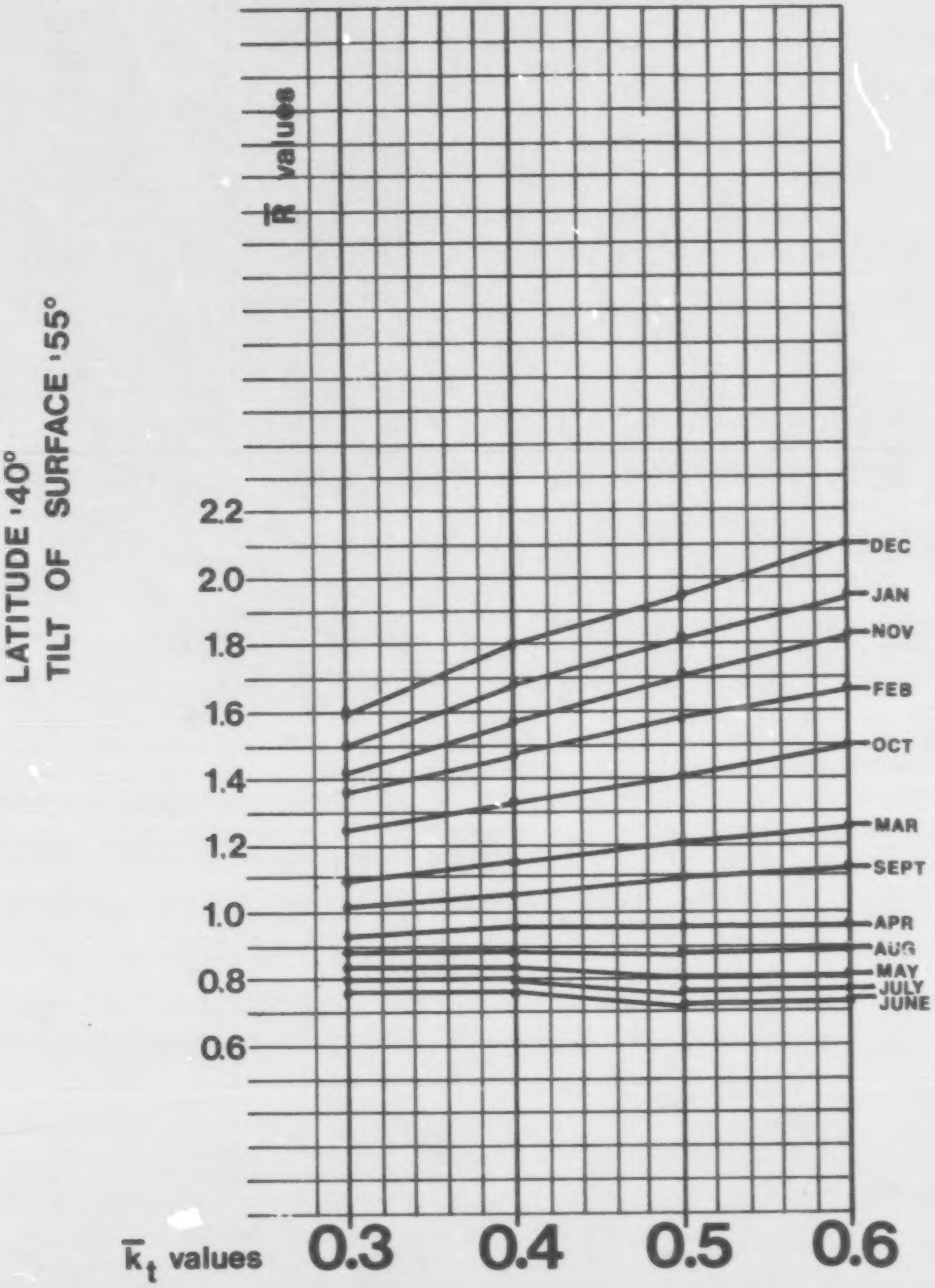
conversion of $\overline{K}_t$ to $\overline{R}$



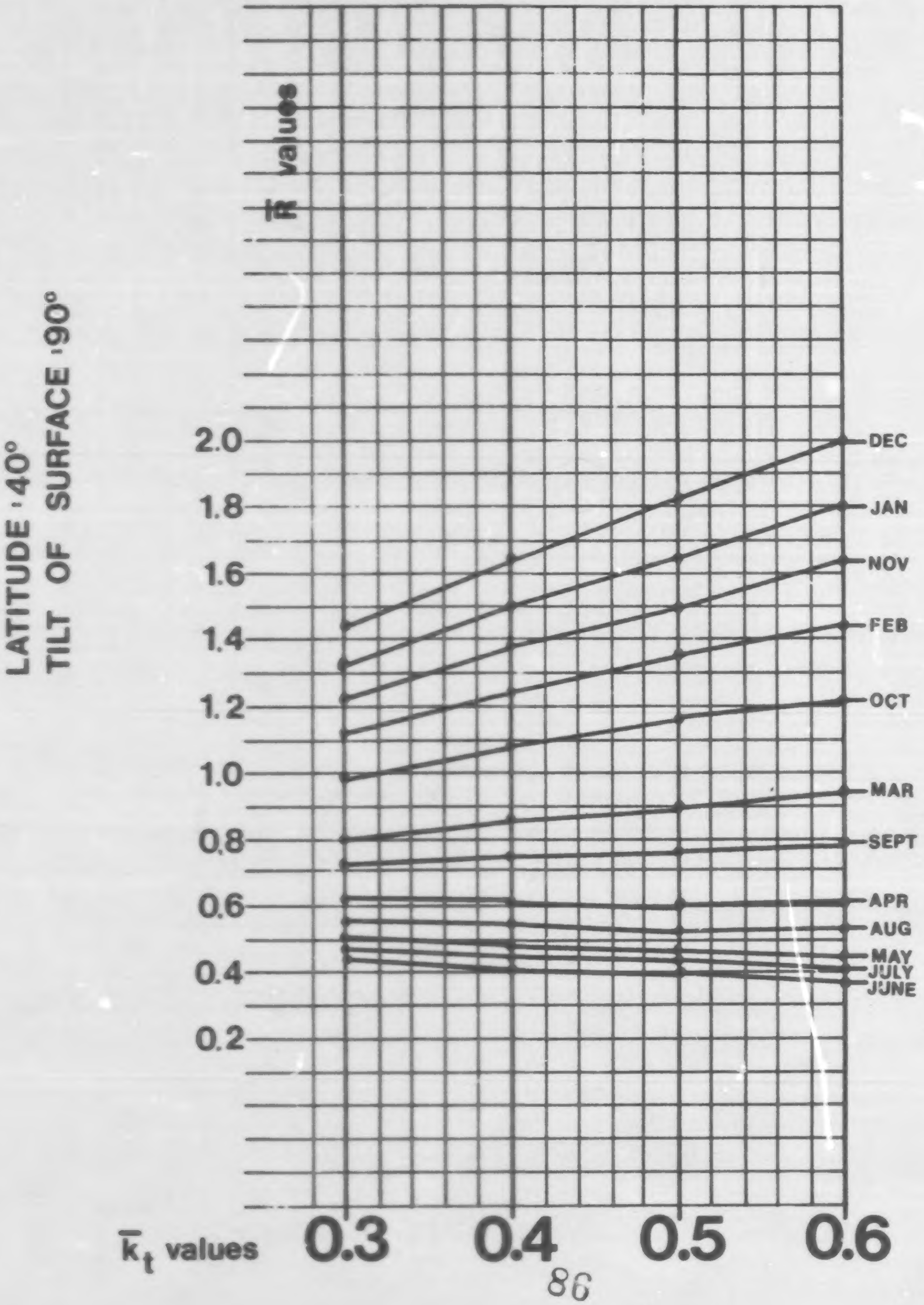
conversion of $\overline{K}_t$ to $\overline{R}$



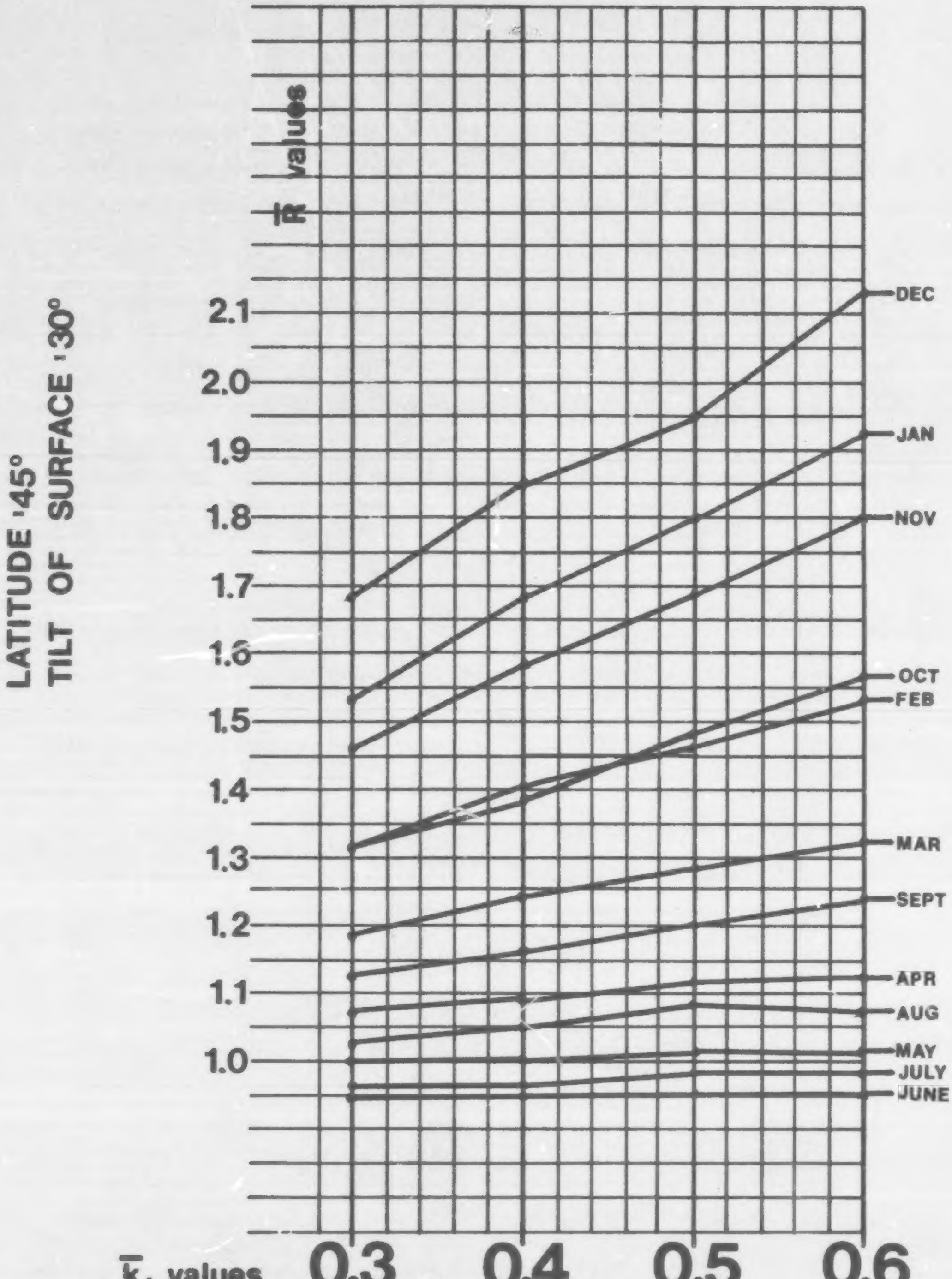
conversion of $\overline{K}_t$ to $\overline{R}$



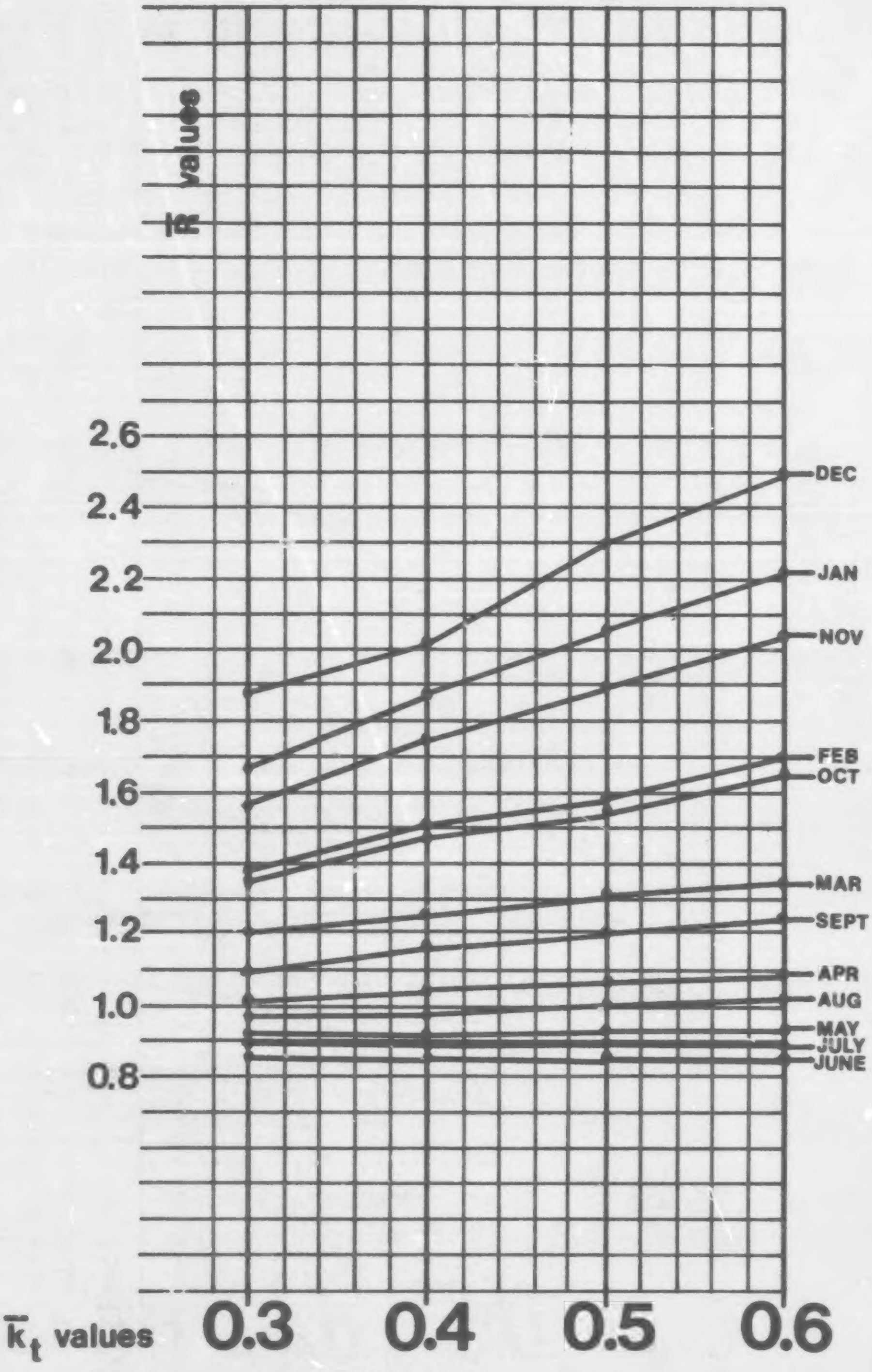
conversion of $\bar{K}_t$ to $\bar{R}$



conversion of $\overline{K}_t$ to $\overline{R}$



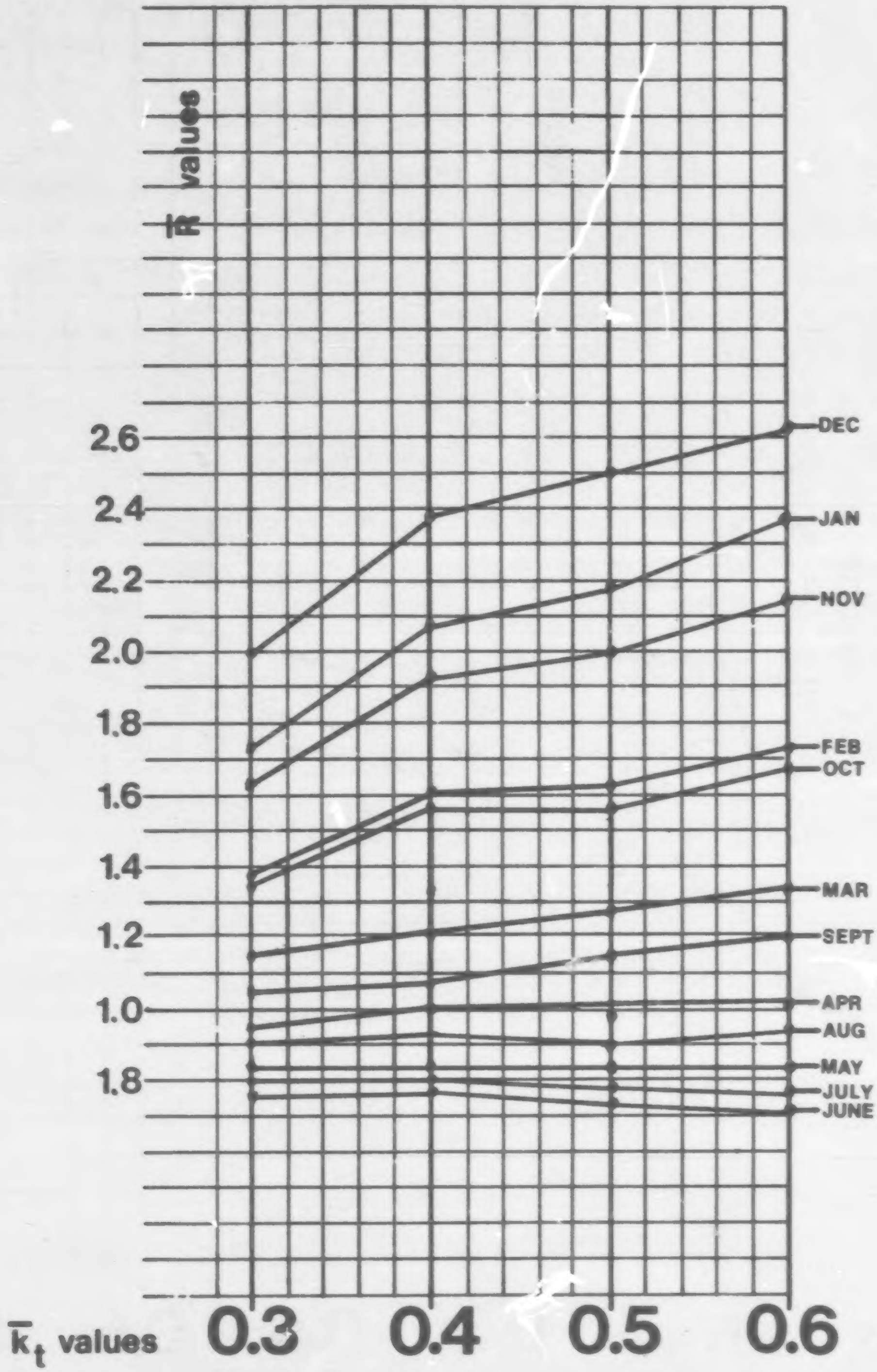
conversion of $\overline{K}_t$ to $\overline{R}$



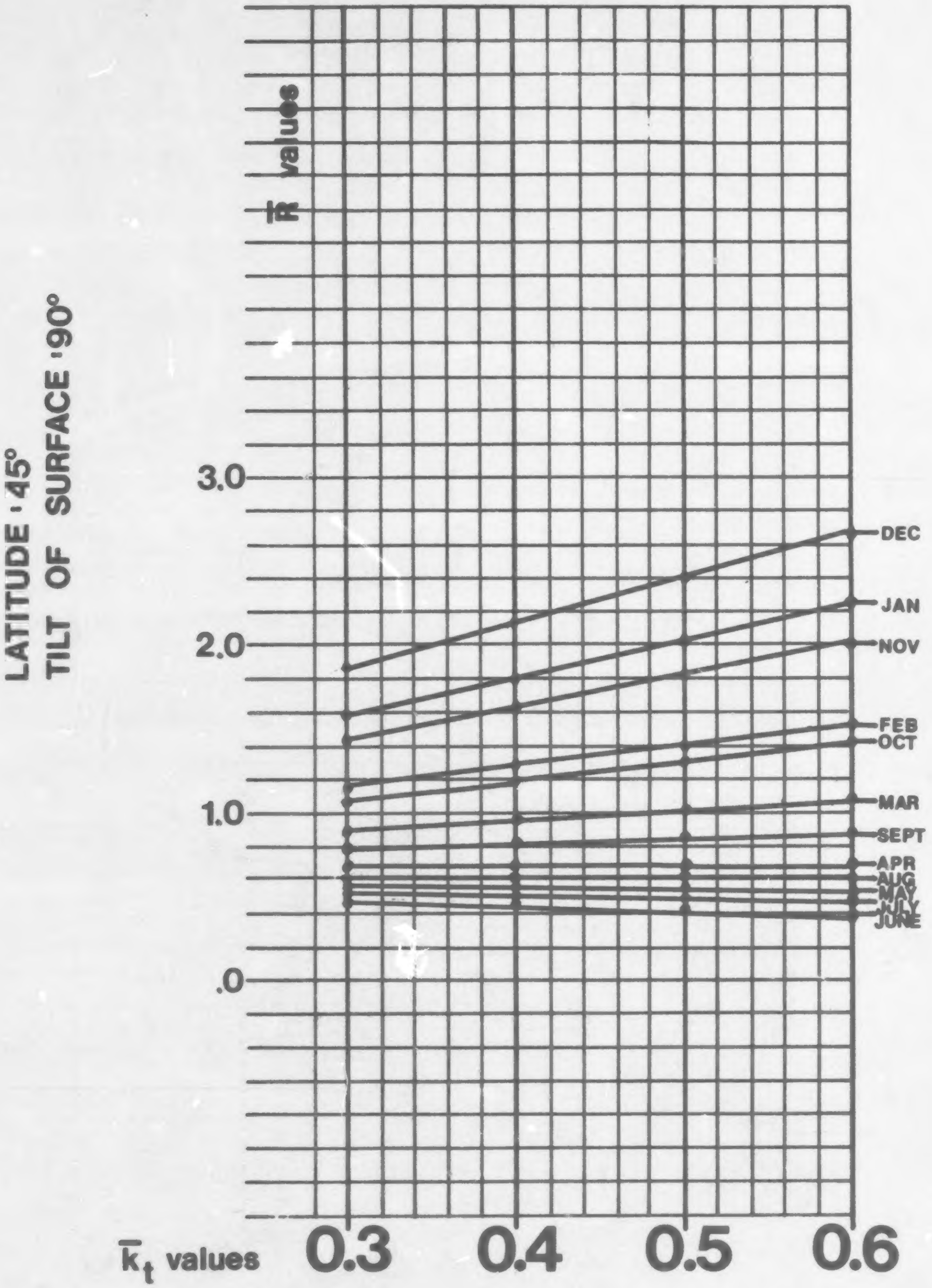
LATITUDE '45°
TILT OF SURFACE '45°

conversion of $\overline{K}_t$ to $\overline{R}$

LATITUDE ·45°
TILT OF SURFACE ·60°



conversion of $\overline{K}_t$ to $\overline{R}$



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measures

Metric Prefix	Common Usage	Scientific Notation
nano	1 billionth	10^{-9}
micro	1 millionth	10^{-6}
milli	1 thousandth	10^{-3}
centi	1 hundredth	10^{-2}
kilo	1 thousand	10^{3}
mega	1 million	10^{6}

energy

1 British Thermal Unit (Btu) = 251.99 calories
= 1055.06 joules
= .00029287 kilowatt-hours
1 calorie = .003968 Btu
1 foot-pound = .324048
1 joule = 1 watt sec
1 kilowatt-hour = 3414.43 Btu

energy density

1 calorie/sq. cm. = 3.68669 Btu/sq. ft.
1 Btu/square foot = .271246 calories/sq. cm.
1 langley = 1 calorie/sq. cm.

power density

1 cal./sq. cm./min. = 221.2 Btu/sq. ft./hour
1 watt/sq. cm. = 3172 Btu/sq. ft./hour

power

1 Btu/hour = 4.2 calories/minute
= .292875 watts
1 watt = 1 joule/sec

flow rate

1 cubic foot/minute = .471.947 cubic cm./second
1 liter/minute = .0353 cubic feet/minute
= .2642 gallons/minute

velocity

1 foot/minute = .508 centimeter/second
1 mile/hour = 1.6093 kilometer/hour
1 kilometer/hour = .621 mph

mass/weight

1 pound = 16 ounces
= .45359 kilograms
1 ton = 907 kilograms
1 kilogram = 2.2046 pounds
1 metric ton = 1000 kilograms
= 2204.6 pounds

liquid volume

1 gallon = 4 quarts
= 3.7854 liters
= 231 cubic inches
1 quart = .9463 liters
1 liter = 1000 cubic centimeters
= 1.0567 quarts
= .2642 gallons

dry volume

1 cubic foot = 28.317 liters
1 cubic yard = .7645 cubic meter
1 cubic inch = 16.387 cubic centimeters
1 cubic centimeter = .06102 cubic inches
1 cubic meter = 35.3145 cubic feet
= 1000 liters
= 1.308 cubic yards

area

1 square mile = 640 acres
= 2.59 square kilometers
1 square yard = .836 square meters
1 square foot = .0929 square meters
1 square inch = 6.4516 square centimeters
1 square centimeter = .155 square inches
1 square meter = 10.7639 square feet
= 1.196 square yards
1 square kilometer = .3861 square miles
1 acre = 43,560 square feet
= 4047 square meters

length

1 mile = 5280 feet
= 1.6093 kilometers
= 1760 yards
1 kilometer = .621 miles
= 1000 meters
1 yard = .9144 meters
1 meter = 39.37 inches
= 3.28 feet
1 centimeter = .3937 inch
1 inch = 2.54 centimeters
1 foot = .3048 meter
1 angstrom = 1×10^{-8} centimeters

temperature

C = 5/9 (F - 32)
F = 9/5 (C + 32)

Landscaping for Energy Conservation

landscaping for energy conservation

introduction

Plants can be used not only as design elements but as functional units that can have significant impact on the amount of energy required to heat or cool buildings. This concept is not a new idea, for it has been practiced by man throughout history. During recent years, the general public and the professional designers have not shown any interest in this concept because energy was cheap and readily available. This is no longer the case, and the use of landscaping for energy conservation must receive recognition on the basis of sheer economics. The U.S. General Services Administration predicts energy costs will double in the next five years. Energy optimized buildings will be a necessity for survival.

I. History. Early American Indians demonstrated an acute awareness of the earth-sun relationship in their desert cliff villages. Note the use of the landform as a passive solar system. (See Figure 1.1)

The ledge above shields the cavern dwellings from high summer sun-the mass of the walls feels cool to the touch. This works only with south facing openings. Not only is it very comfortable in the summer; but in the winter the sun is lower in the south, filling the cliff dwellings with sun. During the day, the sun warms the stone walls which hold the heat for night release. Indian luck or genius!

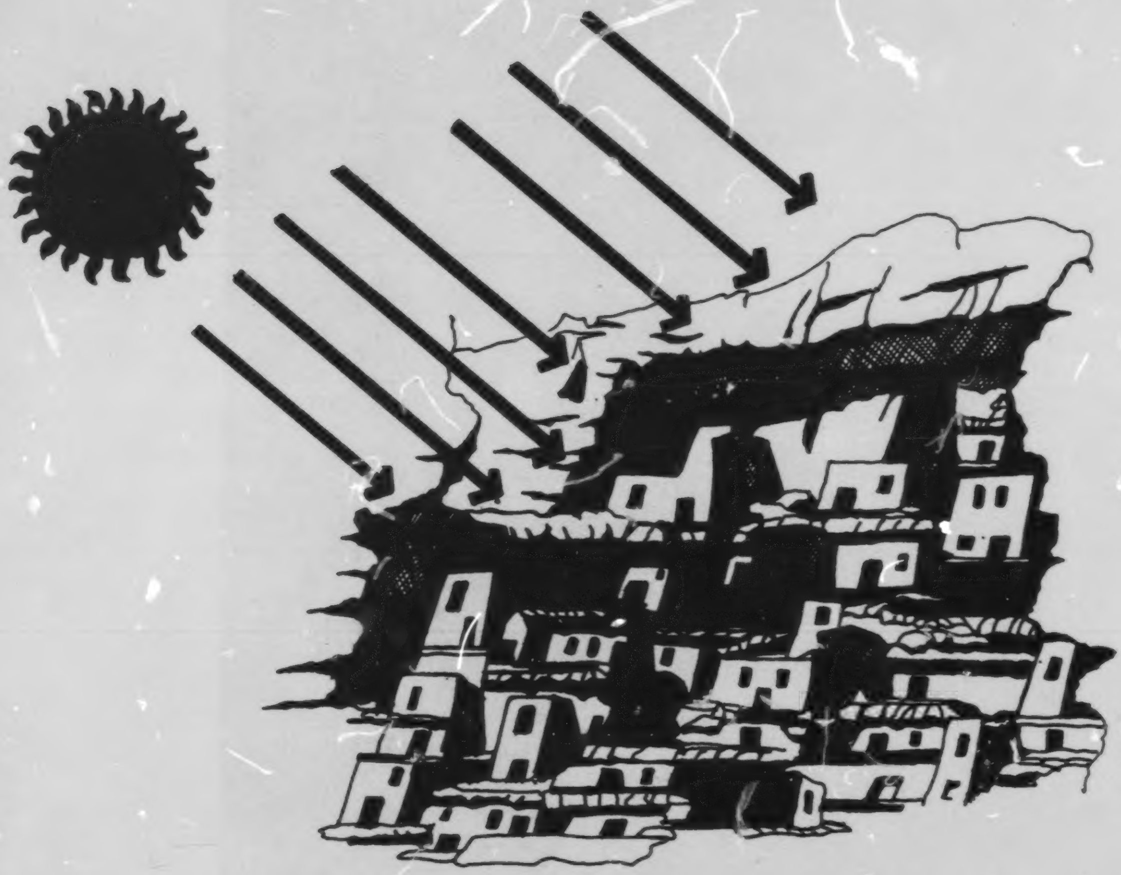


fig. 1.1

history

II. Energy Consumption Cost Analysis (See Figure 2.1). This analysis is based on Carolina Power and Light Company data for the Raleigh area. Note that the typical cooling cost is 40%, the typical heating cost is 25%, the typical lighting cost is 25%, with the other cost at 10% for a typical facility.

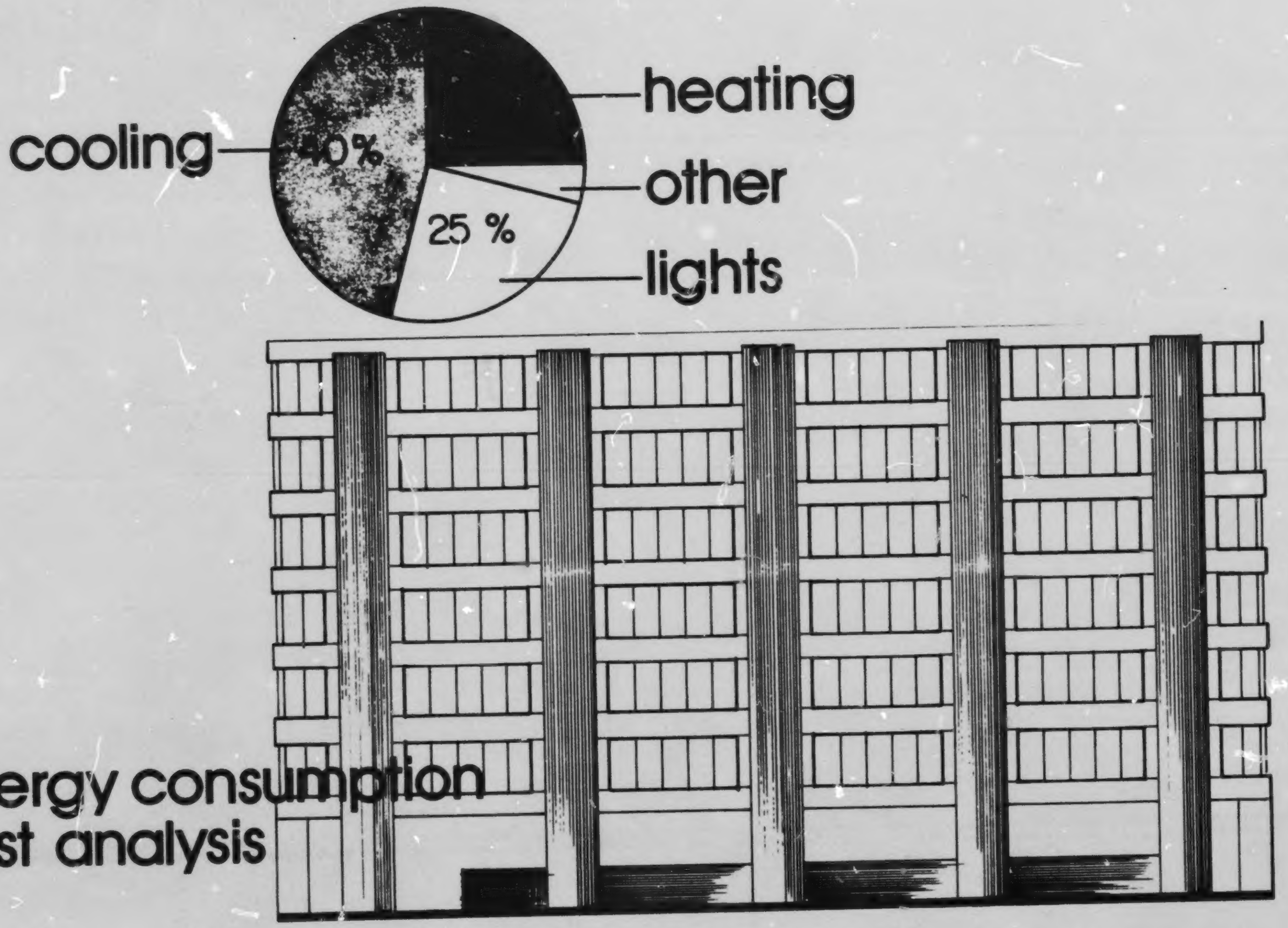
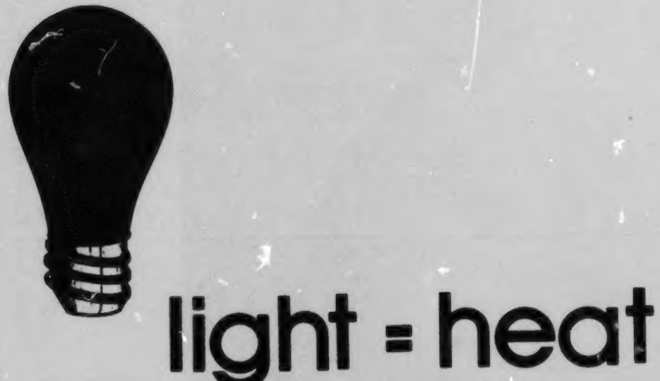


fig. 2.1

energy consumption cost analysis

According to another source, space heating and cooling represents 32% of nation's energy consumption. Proper use of landscape plantings, the proper orientation of buildings and building openings, and the proper insulation of windows could save 20 to 25% of the energy required for heating and cooling. Carrying this concept further, we can identify one other area for energy conservation: the use of lighting only in areas where a task is being performed as opposed to a large generalized use of lighting, which creates a lot of heat. This heat works well in the winter months, but in the summer months this lighting energy must be cooled by cooling energy.

fig. 2.2



light = heat

Remember this formula for it will control all of your conscious thoughts about energy conservation. There are four areas which are instrumental in achieving lower heating/cooling costs. (See Figure 2.3) We will be dealing in this course primarily with concepts pertaining to landscape and orientation.

fig. 2.3

ENERGY OPTIMIZED BUILDINGS

● landscape

⬆ orientation

● *window* insulation

● area lighting

III. Site Orientation. In North Carolina, we are located within the Solar Belt (See Figure 3.1). The Solar Belt is defined as the area within which the amount of solar energy in hours per year reaches at least 2,800-3,600, an amount which can be significantly used as a positive energy source or must be coped with as a negative force requiring energy to cool our environment for living and working.

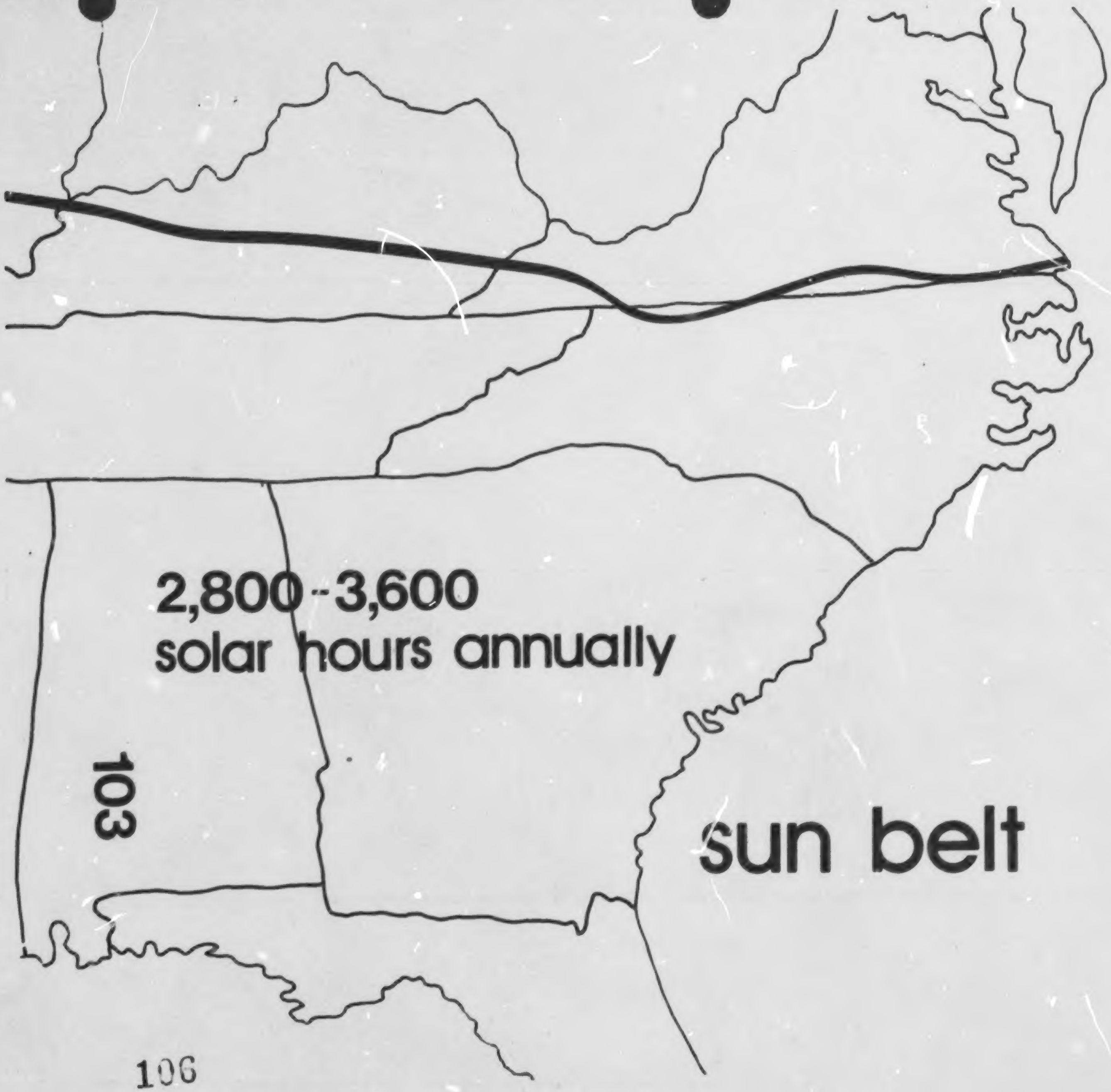
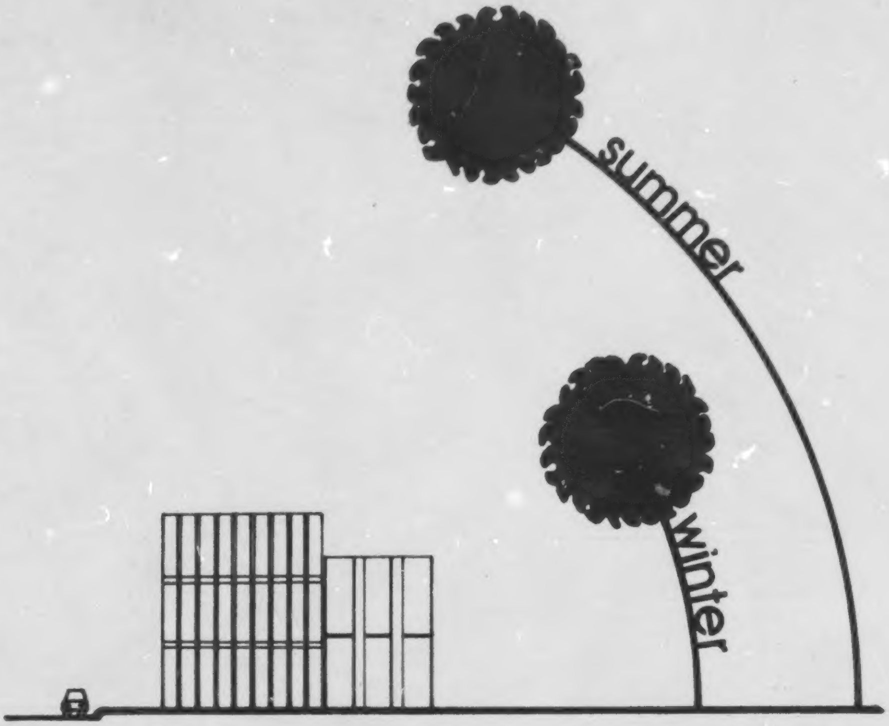
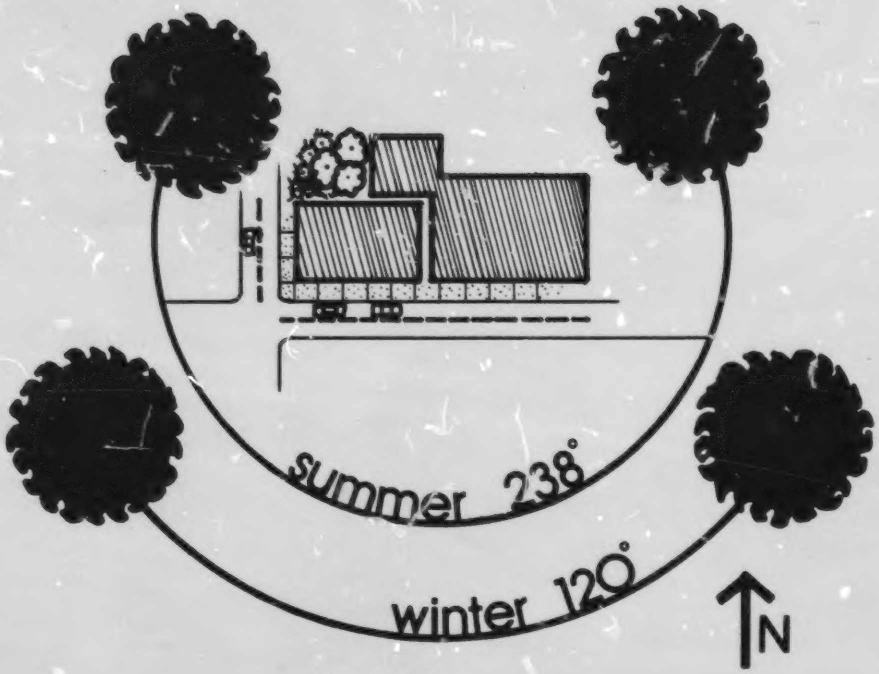

2,800-3,600
solar hours annually
sun belt

fig. 3.1

Sun angles and sun paths vary from summer to winter. (See Figures 3.2 and 3.3)


summer
winter

sun angle fig. 3.2



sun path fig. 3.3

For example, if a typical house is built in our piedmont, every 60 square feet of unshaded west facing window space in the house will increase the peak air conditioning demand in the house by approximately a ton. The same happens to a lesser degree on the east facing window space when the low angle spring and fall sun strikes the glass surface. (See Figures 3.4 and 3.5)

As the sun's path is shortened or extended, depending on the season, certain facades of the building will receive varying amounts of direct sunlight. On a true south oriented structure, the south face receives approximately the same number of solar hours regardless of the season. The east and west faces, however, receive much less sunlight in the winter than in the summer. In the Piedmont, on a true south facing building, the south facade will collect approximately six hours of direct sun every day of the year. The east and west faces combined will collect approximately four hours in the winter and eight hours in the summer.

By interpolation we can see that the east and west faces receive approximately six hours of heated low angle sun in the spring and fall months. It is not uncommon for many of our buildings to be running a cooling cycle for eight months out of the year, versus a heating cycle of only four months. To reduce summer cooling expenses, plant deciduous trees on east and west facades as well as the south face.

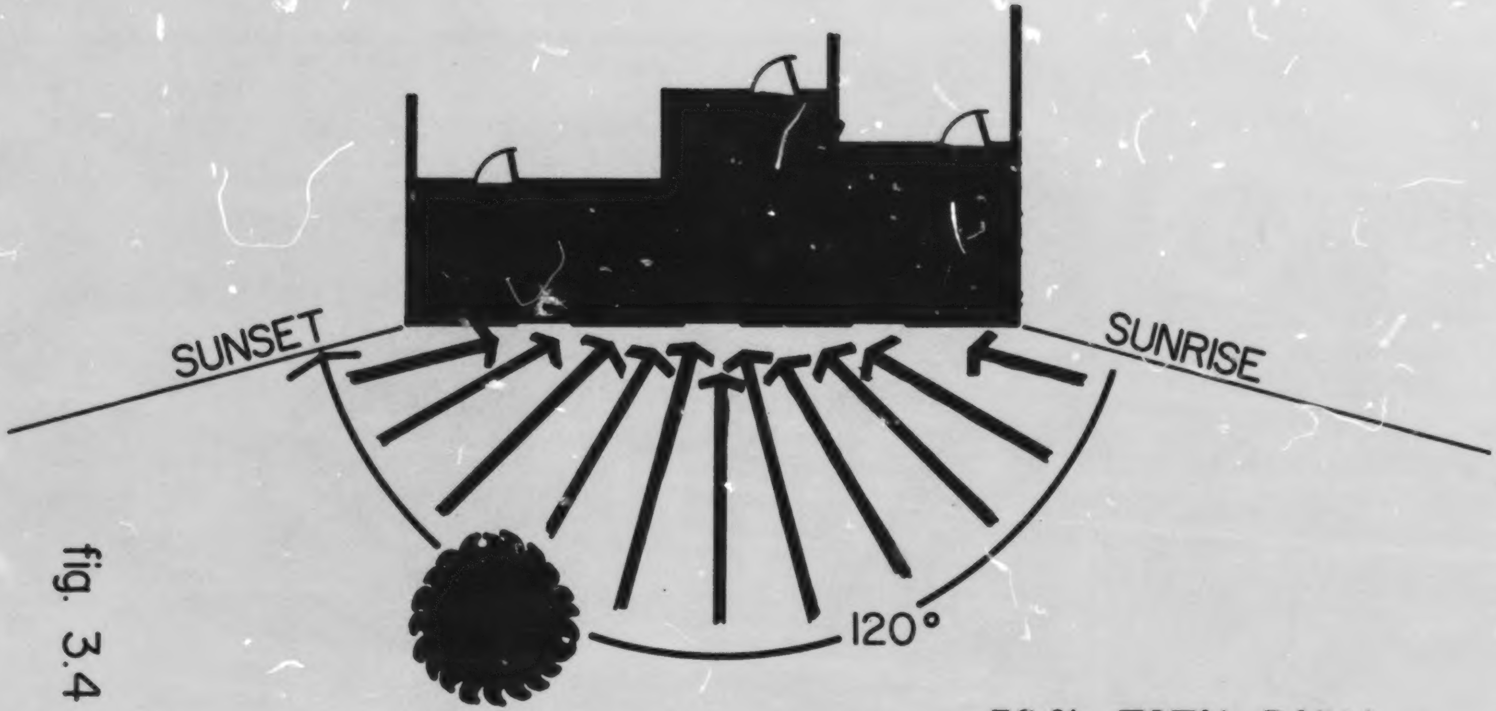

SUNSET
SUNRISE
120°

fig. 3.4

50 % TOTAL DAILY
SOLAR RADIATION
AVAILABLE

south facade - **summer**

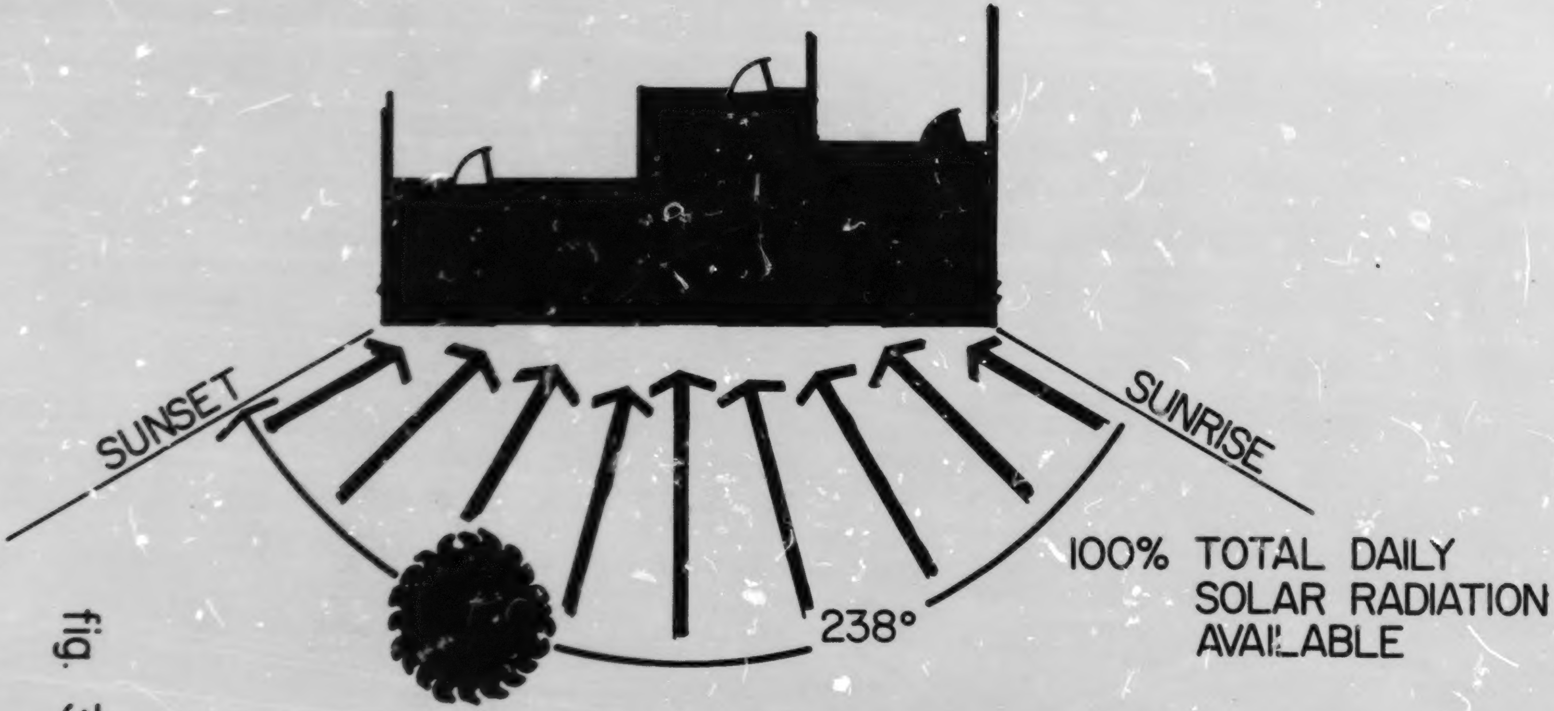

SUNSET
SUNRISE
238°
100% TOTAL DAILY
SOLAR RADIATION
AVAILABLE

fig. 3.5

south facade - **winter**

When selecting a site for development, certain qualities should be kept in mind.

1. Site orientation for southern exposure is desirable. Solar energy and attention to natural systems and forces can be beneficial to conventional buildings as well as "solar" structures. A desirable site will receive direct sunlight.
2. If the site has a slope, it preferably should be south or near south facing.
3. The proposed building location(s) should not be obstructed from solar gain by structures on adjacent properties.
4. Wooded sites with large trees already established are most valuable, providing the trees can be preserved.
5. The site should be well drained. Water resources which originate or cross a site are also generally desirable.
6. Soils are also a consideration in site selection. If the site is partially fill dirt, it should be well settled before any building takes place. Soil composition should not be extreme (i.e., sand or clay). Plant growth and drainage are the prime concerns relating to soil composition. For accurate analysis, soil tests and borings can be taken to determine the quality of questionable soil.

IV. Influencing Factors. The major factors that affect human comfort are air temperature, solar radiation, wind and humidity. Perception of heat or cold can be a result of any one or a combination of these influences. The bottom line for the use of energy in buildings is to establish a feeling of comfort. Through the use of proper plantings and landscape design, a comfort zone can be created inside the building. For example, the direct sun rays coming into a building through glass areas which have no protective overhang or tree cover (See Figure 4.1). Create, inside the building, a hot glarish climatic zone to work in with colder areas just beyond. These areas are termed microclimatic variations for they exist as smaller climates within the larger building climate. The only control in the building is through internal means or by changing clothing. Through landscape design the impact of microclimatic variations can be tempered to help insure one's feeling of thermal comfort.

Screen plantings and earthforms can be utilized on northern exposures and entrances to insulate from winter winds. Deciduous trees can be used to filter light and provide shade in summer time, while allowing penetration of direct sunlight in winter. Groundcovers and shrubs can be used to cut glare from hard paved surfaces.

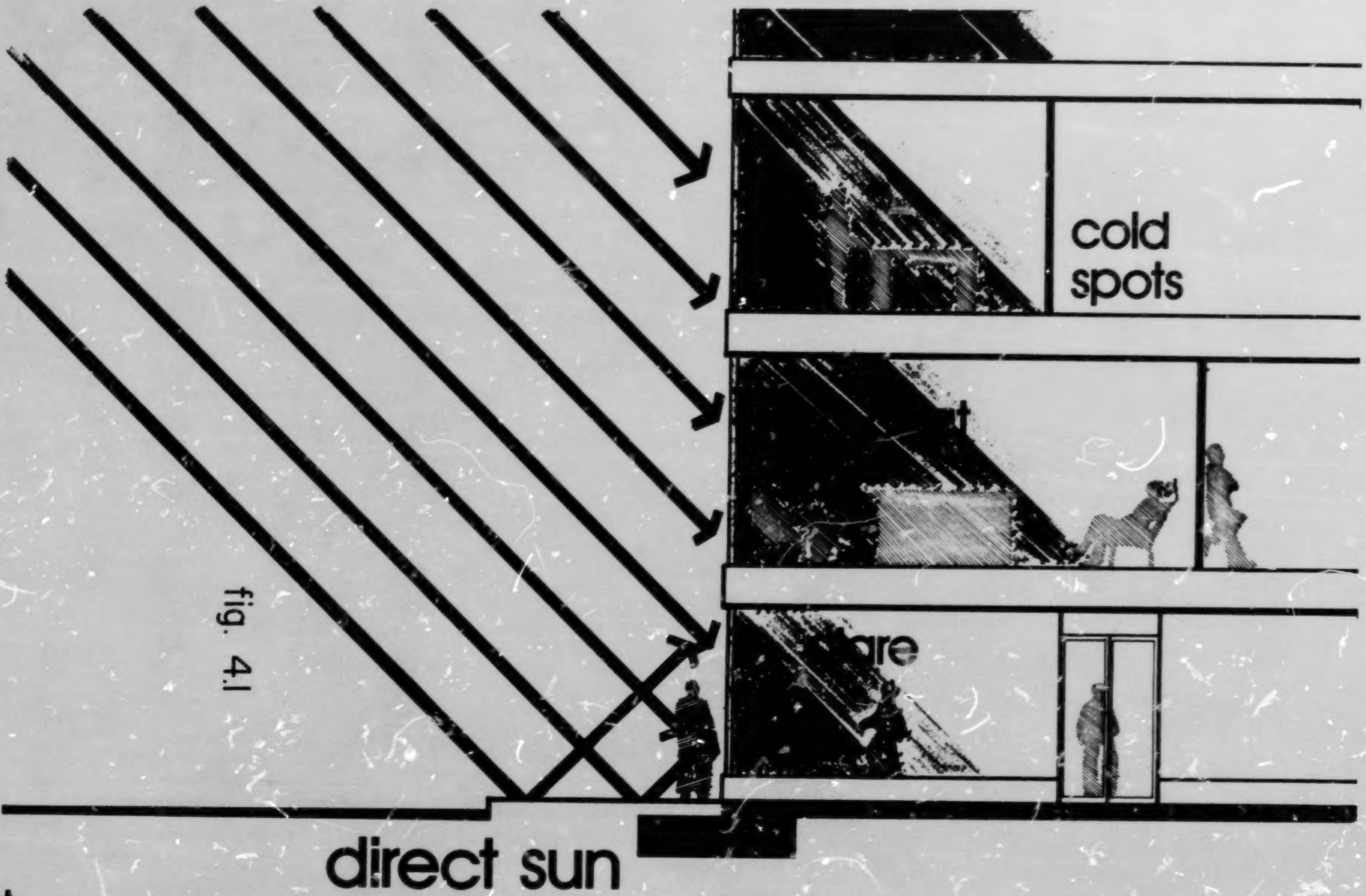

cold
spots
are
direct sun

fig. 4.1

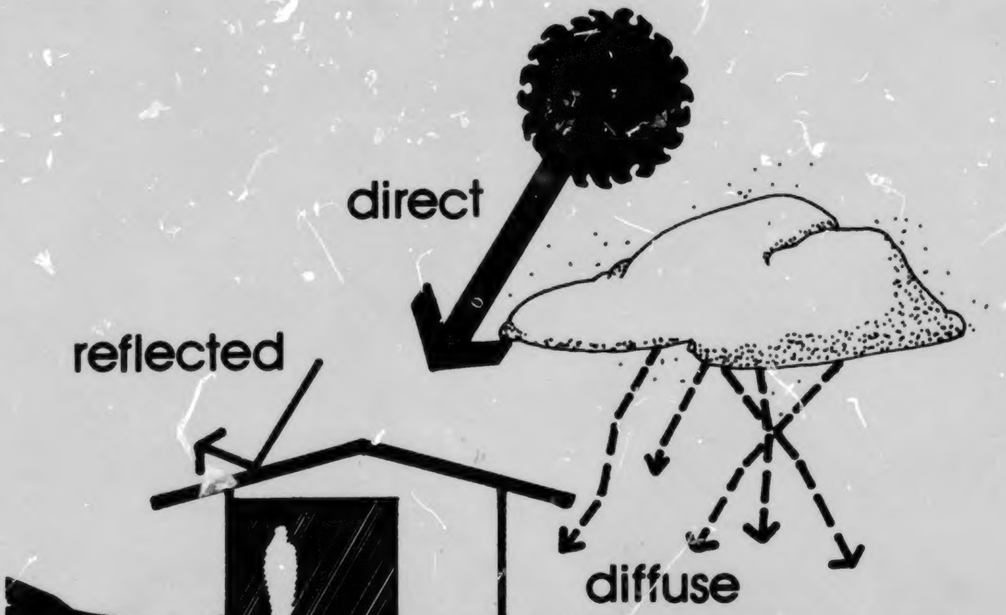
V. The Difference Between Climate and Microclimate. There is an important distinction between climate and microclimate which must be understood before effective landscape design can be accomplished.

Climate refers to the general character of temperature, solar radiation, humidity, wind, and precipitation that prevails over a region of considerable geographical area.

Microclimate refers to the specific or localized character of each of these elements as they are modified by local typography, slope, orientation, vegetation, presence of water, buildings, and other landscape elements such as fences, walls and pavements. All site characteristics are tools which should be used to create a microclimate best suited to the needs of the client.

VI. Temperature. The normal tolerable average temperature range is between 60 to 80 degrees. If the average falls above or below this zone, heating or cooling is required. The amount and duration of sunlight affects heat radiation on structures and humans. There are several different types of radiation (See Figure 6.1). Depicted are:

1) Direct radiations from the sun.
2) Reflected radiations from light ground surfaces.
3) Diffused radiations from and through clouds .



types of radiation fig. 6.1

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VII. Radiation.

It takes a careful evaluation of natural and structural materials to understand the full impact of these various types of radiation. However, certain basic assumptions can be made. The most simple relationship is the one which involves the selection of plant materials which will screen or deflect the direct and diffused radiations from striking the ground or building surfaces.

Obviously, the placing of tall deciduous trees between the west, south and east faces of the building would keep these building faces shaded from the radiations in the spring, summer and fall while allowing the warming winter radiations through as the leaves are naturally dropped from the trees.

Trees must be selected which will grow fast and tall. The maples and oaks, for example, will grow to a height of sixty feet in thirty years; whereas, japanese maples and dogwoods will only reach twenty feet in thirty years. Fifty years would find the maples and oaks reaching a height of seventy to eighty feet, whereas the smaller japanese maples and dogwoods would remain at about twenty feet in height. A deciduous tree, as it changes throughout the seasons, can be considered a passive system within itself. (See Figures 7.1 and 7.2) The maximum height and rate of growth are critical factors in the selection of plantings for controlling radiation. (See Figure 7.3) An even more effective screening of buildings can be accomplished by careful placement of masses of deciduous shade trees. (See Figure 7.4)

Vines have a potential when understood. With proper structural support vines can provide overhead shade. They can also reduce the amount of heat gain when growing on building walls. For example, deciduous vines such as Boston Ivy could cover the masonry areas of a building and their green foliage mass becomes an insulating blanket for keeping the structure cool in the summer. In the winter the leaves would fall off, leaving the masonry elements open to the sun's rays which would then allow the storage of warmth in these elements by day to become a thermal buffer during the nighttime. (See figures 7.5, 7.6 and 7.7)

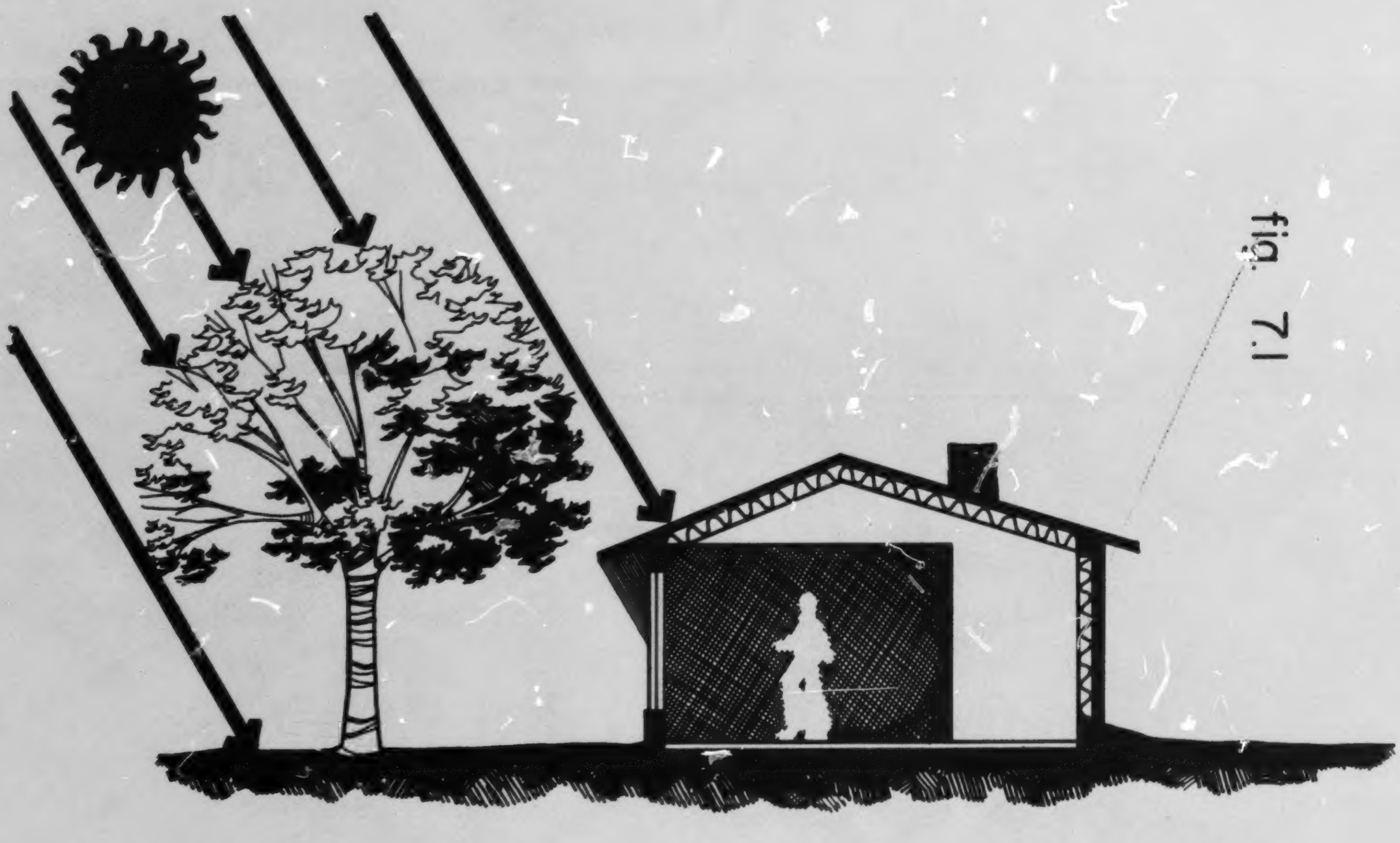

fig. 7.1

summer - deciduous tree

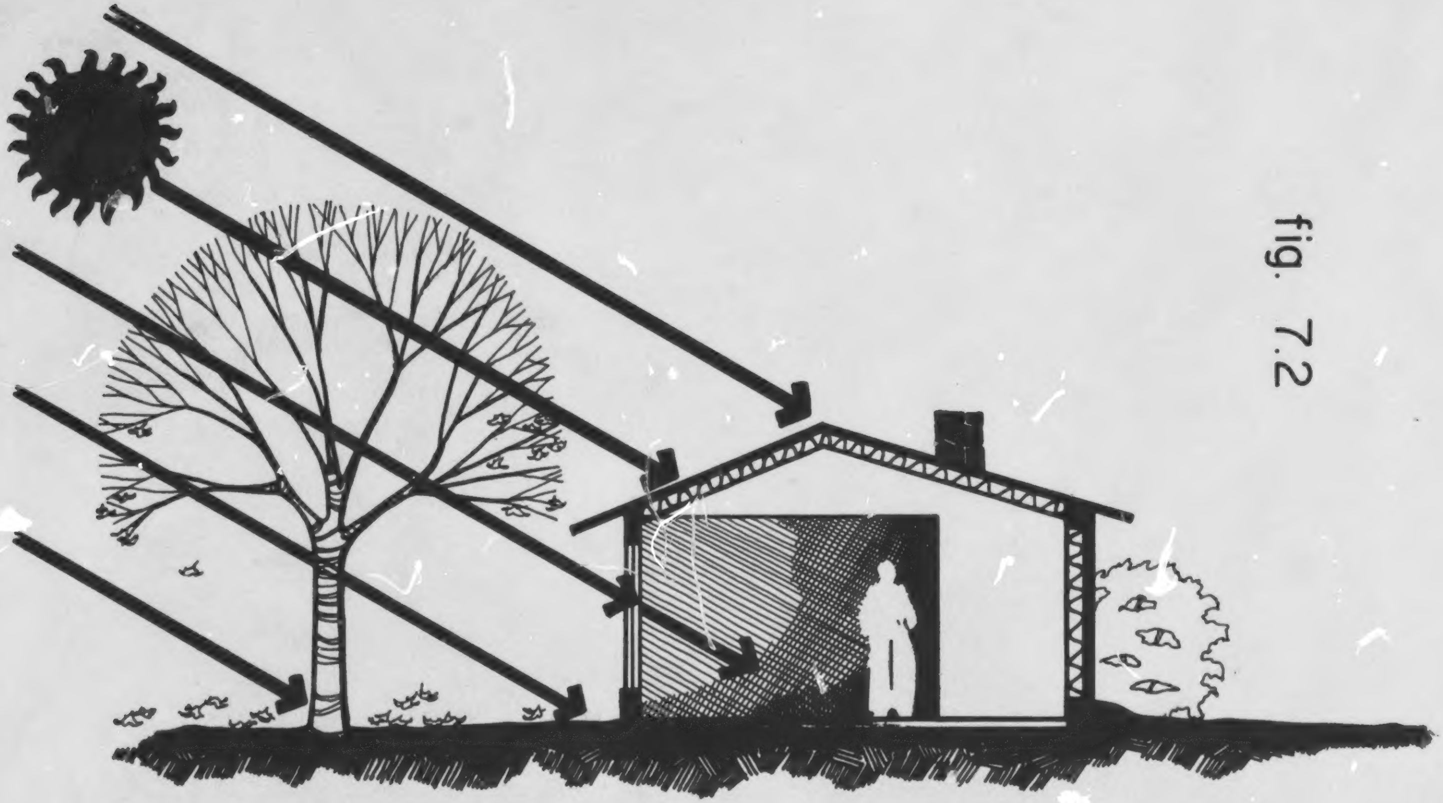

fig. 7.2

winter - deciduous tree

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122

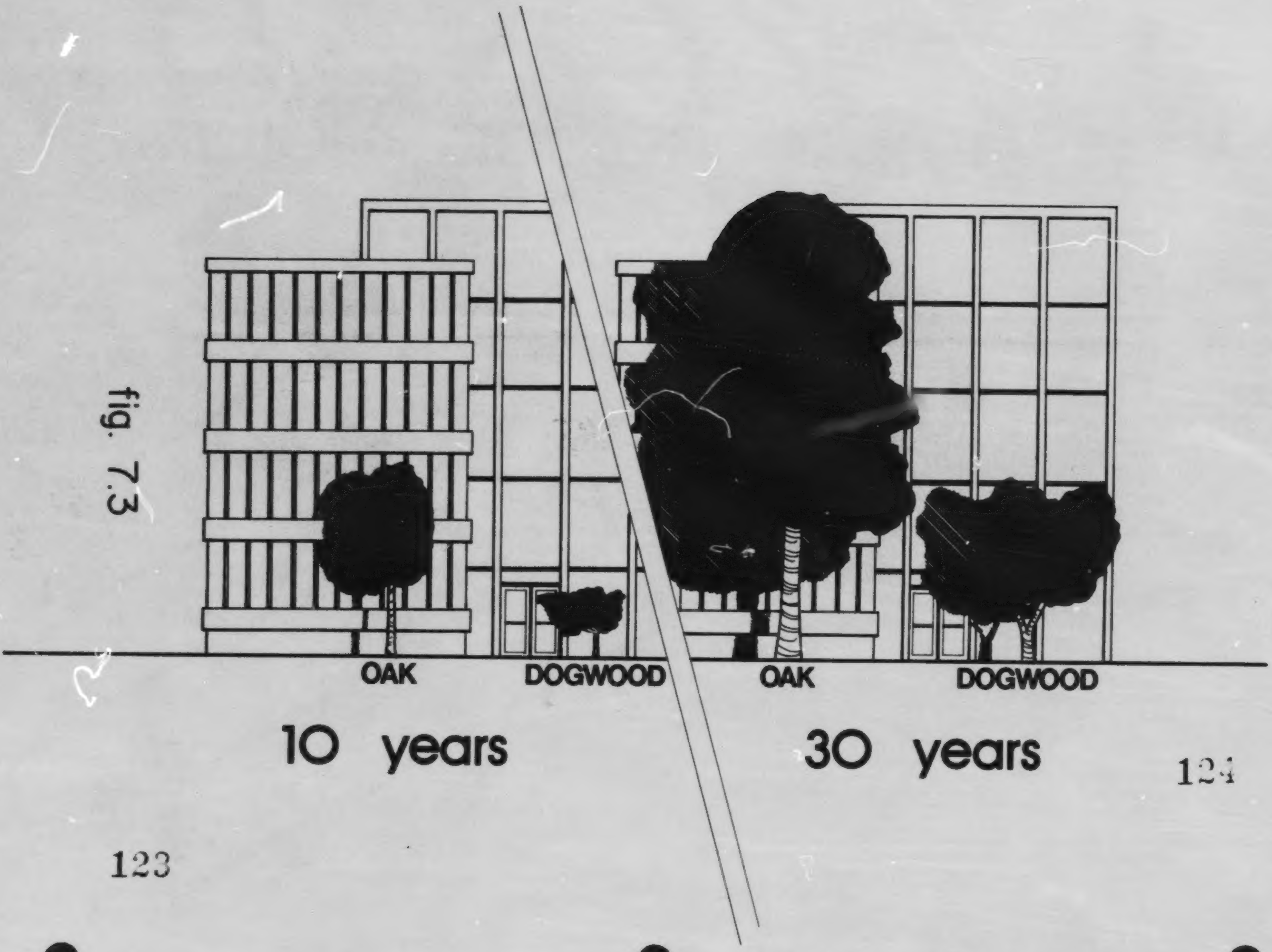

OAK
DOGWOOD
OAK
DOGWOOD
10 years
30 years

fig. 7.3

124

123

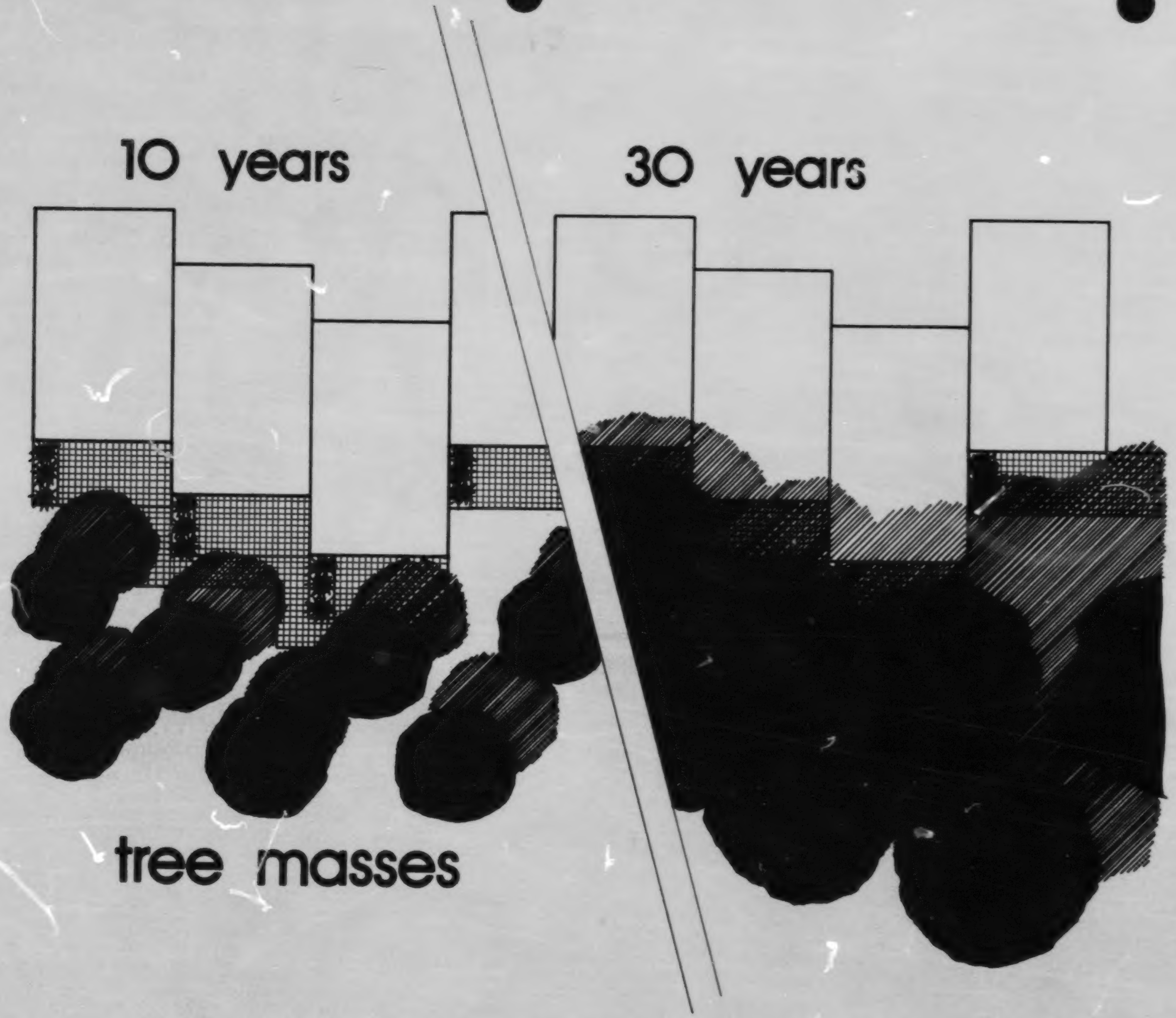

10 years
30 years

fig. 7.4

tree masses

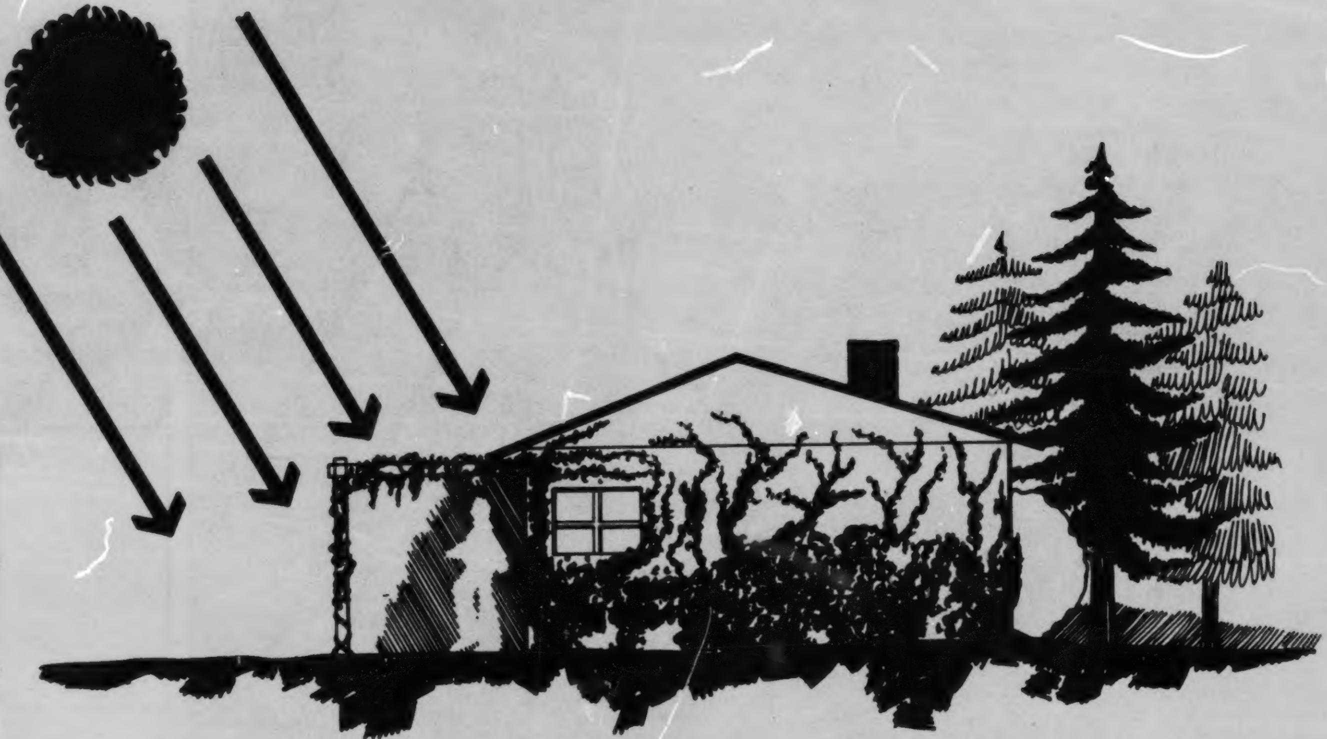


fig. 7.5

deciduous vines - summer

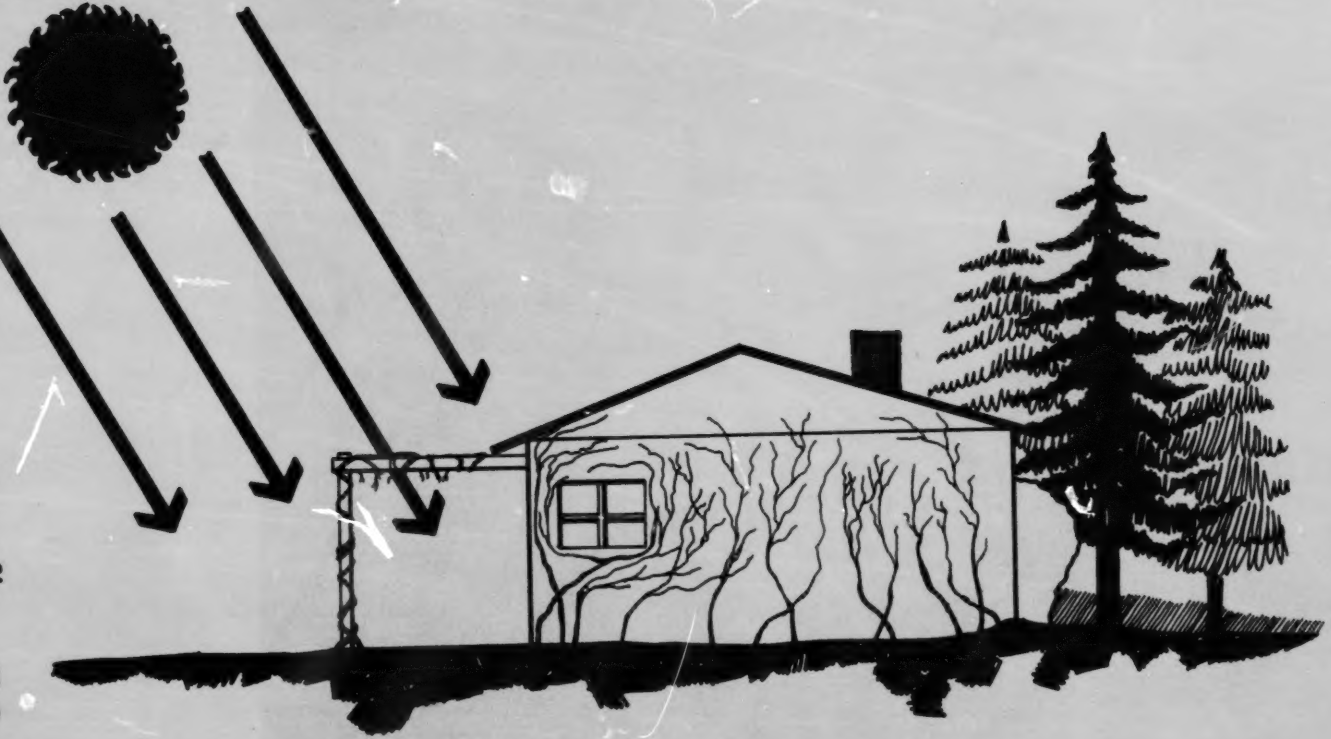


fig. 7.6

deciduous vines - winter

The examples shown in figure 7.7 depict vines growing directly on masonary walls. An alternative method would involve the attachment of a trellis to the wall for the vines to climb on. This method minimizes damage to the masonary, since the roots are attached to the climbing structure. Spacing of boards on the trellis should be generous (1' - 1 1/2') so that solar gain is not seriously reduced.

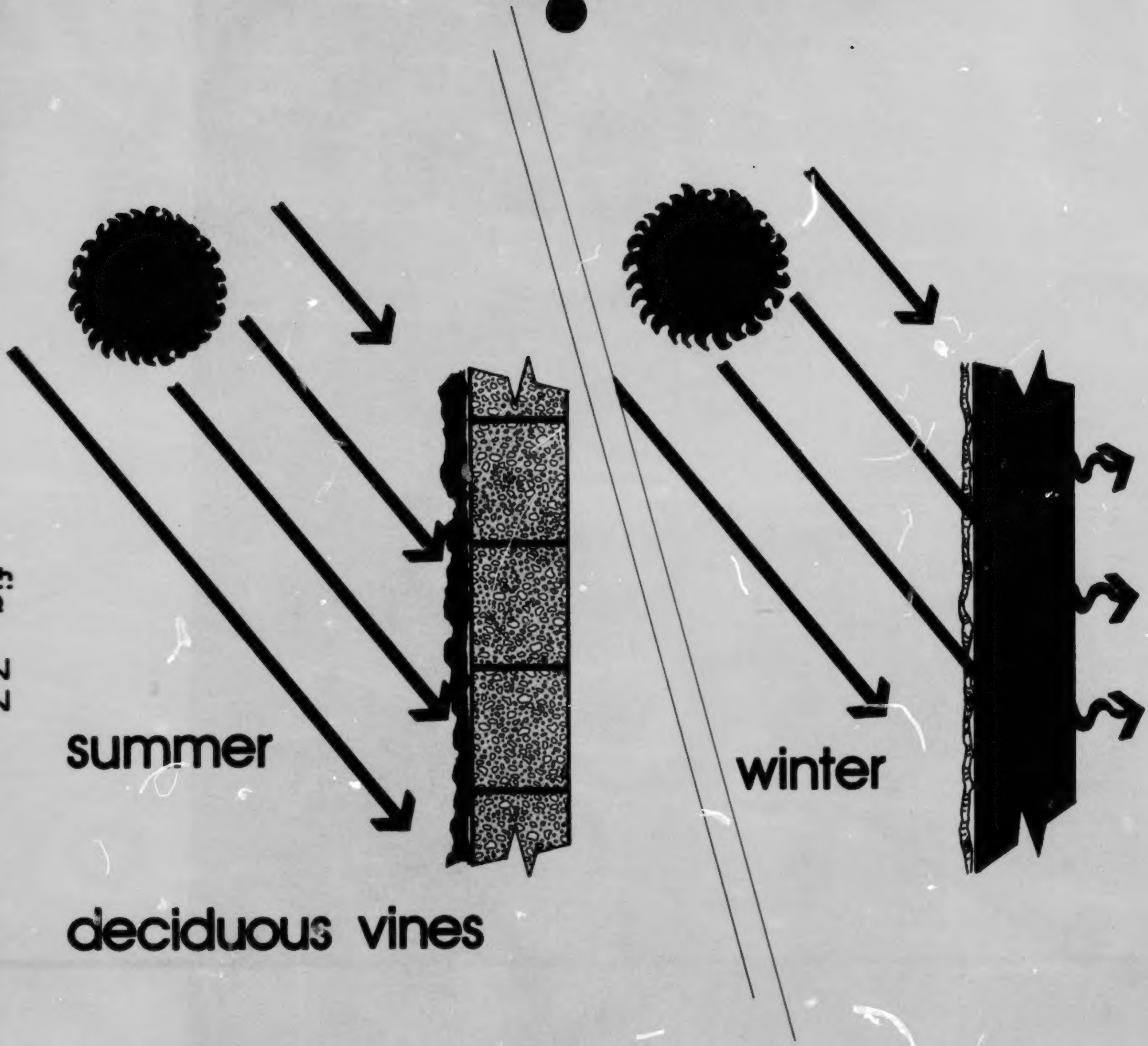

summer
winter

fig. 7.7

deciduous vines

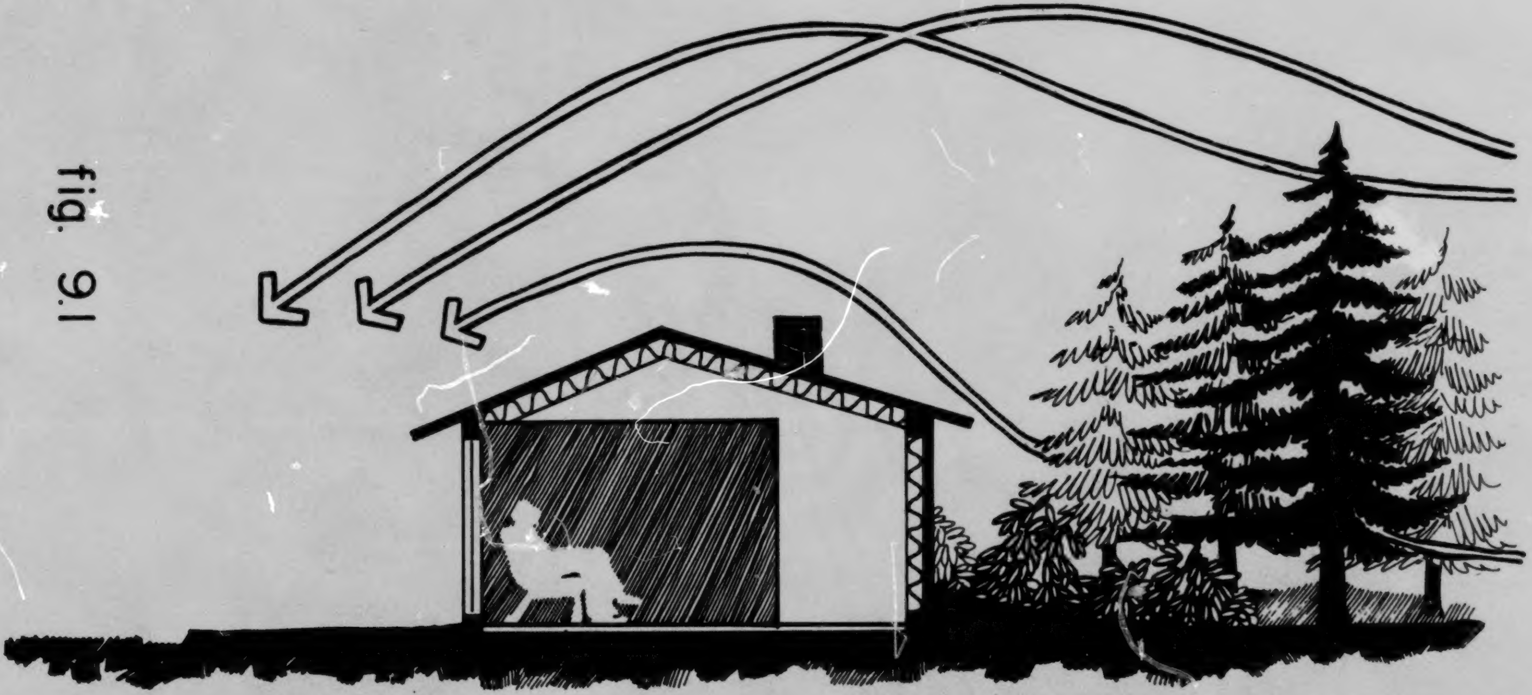
VIII. Humidity. High levels of moisture in the air will detract from human comfort. Since evaporation/cooling involves the release of moisture into the air, highly saturated air will retard evaporation and prevent cooling Dry air is a better insulator than wet air. Moist air as a conductor will allow cold to penetrate, thus reducing the effectiveness of insulating materials. Areas with a high percentage of moisture in the atmosphere require plant materials that encourage air circulation, while areas lacking humidity need to exploit landscape features that will add to the moisture content.

Air circulation can be created by using plant screens to divert and channel breezes to areas otherwise sheltered from wind currents. This will reduce humidity by forced evaporation. Plantings should be used to deflect rather than filter air flow. Reduce undergrowth to allow free flow of wind.

To increase moisture content, several measures are available. Since plants, particularly large broadleaf trees, transpire large quantities of water in a day's time, merely increasing the volume of plant materials will add to moisture present in the air. Otherwise, bodies of water may be incorporated to supplement humidity by evaporation. Refer to Core Section (page 16) for humidity and temperature correlations.

IX. Wind. Wind has tremendous influence. Its interaction with temperature factors can result in either positive or negative impacts depending upon the combination. By knowing the seasonal and daily wind patterns in combination with the orientation and shape of buildings, fences, earth forms and plantings, the landscape designer can take the best advantage of the wind forces or minimize them when the impact is negative. Evergreen windbreaks can be used as a protective device to screen off(See figure 9.1) cold winter winds from the north. Refer to the core section (page 17) for wind flow patterns.

fig. 9.1



evergreen windbreak

Evergreen windbreaks can be used as a buffer to control or change wind patterns. (See Figures 9.2 and 9.3)

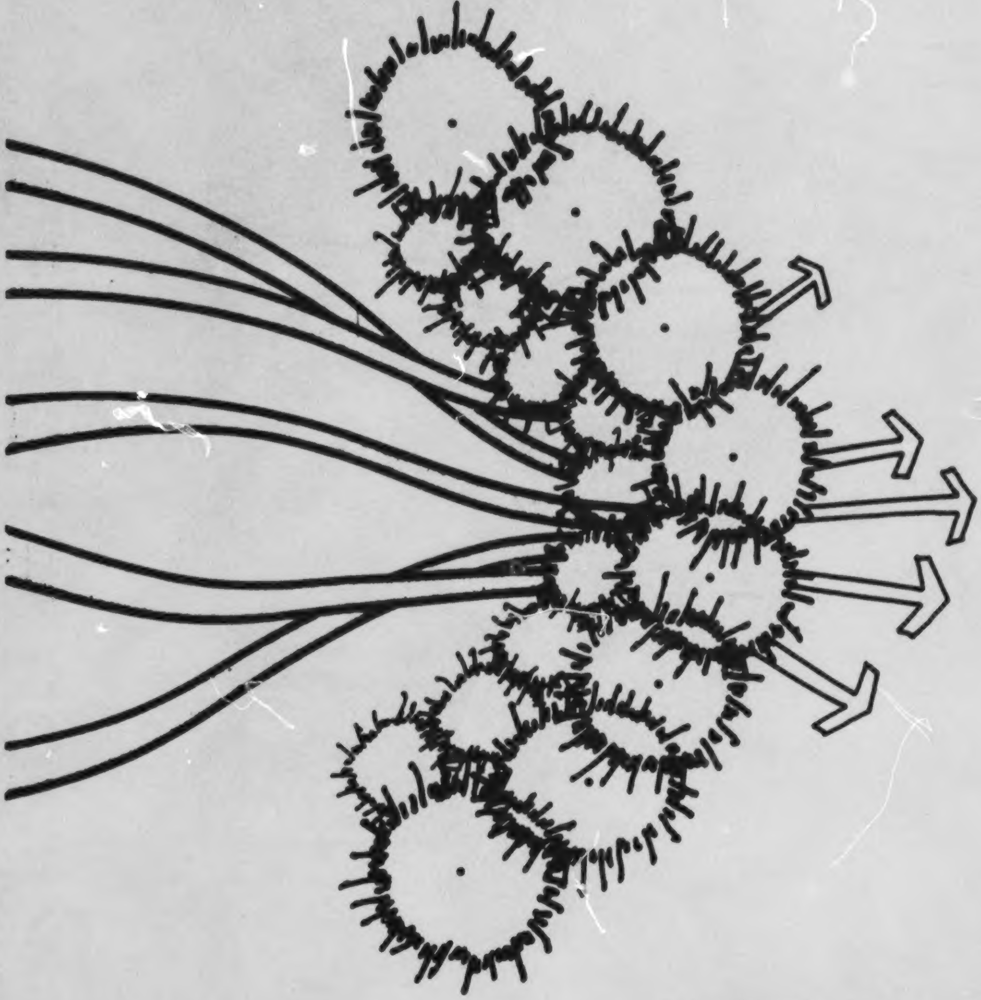


fig. 9.2 wind filtration

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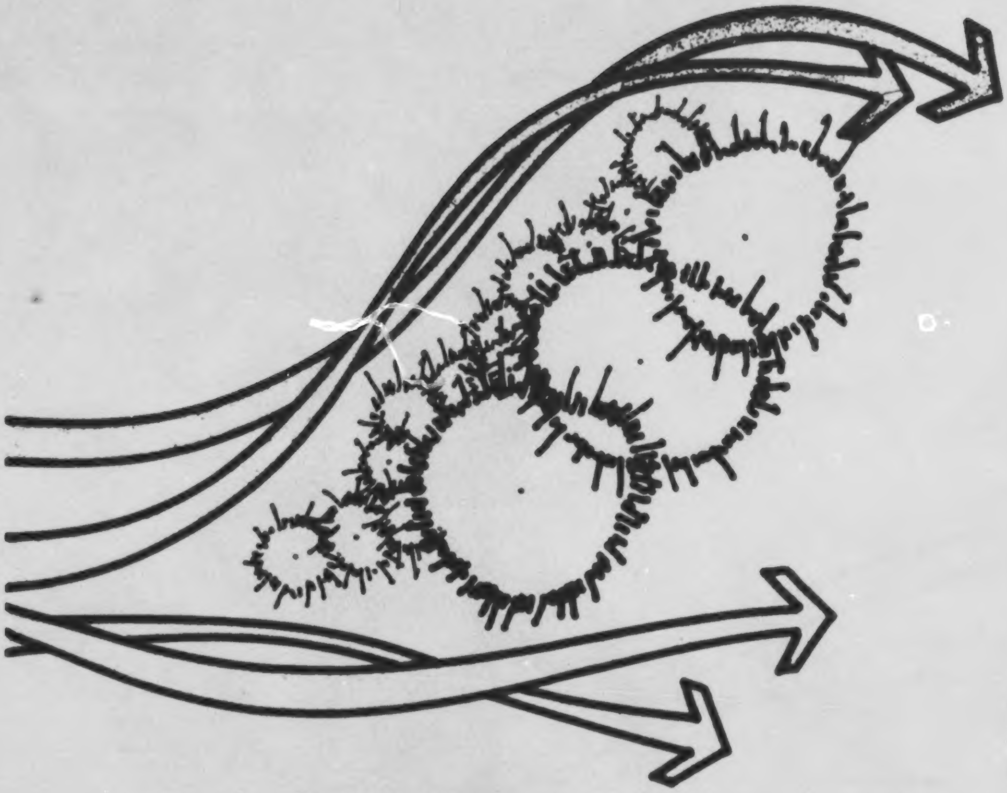
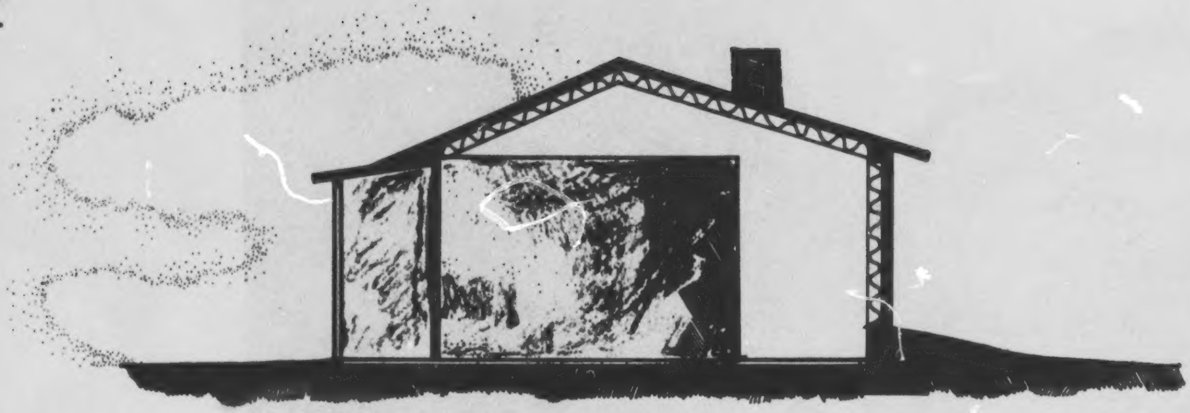


wind deflection **fig. 9.3**

Deciduous screen windbreaks can be likewise used to deflect warm breezes in the summer while allowing them to penetrate their defoliated mass during the winter months.

fig. 10.1



vestibule

X. Thermodynamic Effects. The final component to consider in energy conservation design is the understanding of the thermodynamics of microclimatic factors. The laws of thermodynamics maintain that heat cannot move from the colder body or mass to the warmer one. Rather, it is the warmer of the two bodies that loses heat and the colder one that gains. In fact, heat will seek out cold and there is a constant attempt at equilibrium.

The two ways that proper landscape design can minimize this heat exchange is by using plant materials in an effective way to cut down heat loss from a building in the winter and heat gain to a building in the summer. We have mentioned wind previously for a reason. The turbulent or laminar wind thrusts put pressures on all fixed elements in their paths. In a building, the cracks or openings around windows and doors allows this wind pressure to actually force heat or cold into the interior spaces.

Another remedy from the past to cut down on heat loss was the vestibule. (See Figure 10.1) This two-door airlock cuts down on heat loss or gain simply because it isolates a neutral zone of heat and air pressure through which excessive changes of temperature will not occur due to this buffer zone.

XI. Summation. Common sense is the basic plan for energy efficient landscapes. Trees, shrubs, ground covers and turf are the basic tools that can be used to create aesthetically pleasing yet energy conserving designs. A landscape that uses the sun's heat energy for winter space conditioning and denies this same sun's heat energy for summer space conditioning is the best solution.

Deciduous trees are the major plant element to minimize the negative aspects of summer radiation while allowing the positive aspects of winter radiation when the leaves have fallen.

Evergreen trees block the sun's radiation in all seasons; therefore, they should not be close to a building in areas where the winter solar heating is needed. Their chief value is as windbreak plantings where their evergreen mass breaks up the cold winds, particularly from the north.

Shrubs are not as easy to use as climatic conditioning devices. Their size and growth patterns make them suitable for use with taller tree plantings for the purposes of blocking, channeling or deflecting. (See Figures 11.1 and 11.2)

Groundcovers are useful in stabalizing soil. Additionally , groundcovers can reduce reflected radiation when placed below windows and around buildings.

Vines are also considered groundcovers as they serve the same functions. Vines are additionally useful for radiation control because they are climbers which can cover structures as well as ground. Some varieties are deciduous. Deciduous vines perform best as solar radiation control tools. Evergreen vines serve best as windbreaks when used on walls or fences.

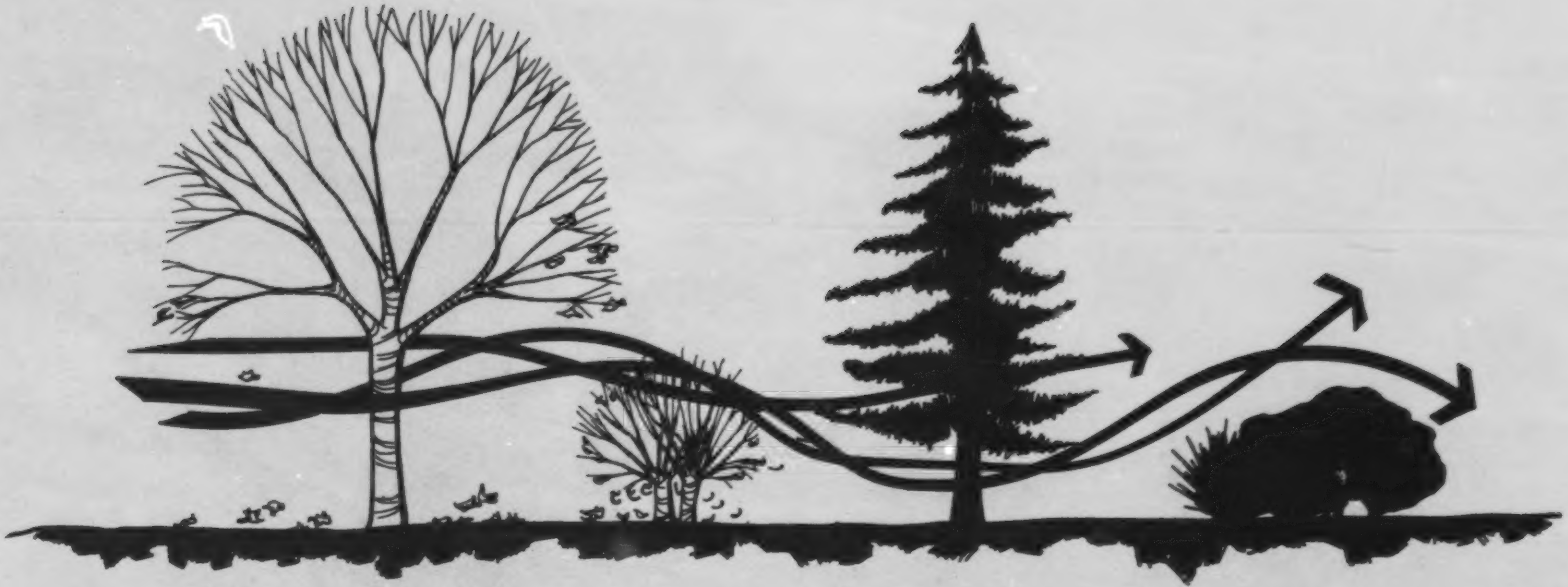


fig. II.1

incomplete barriers

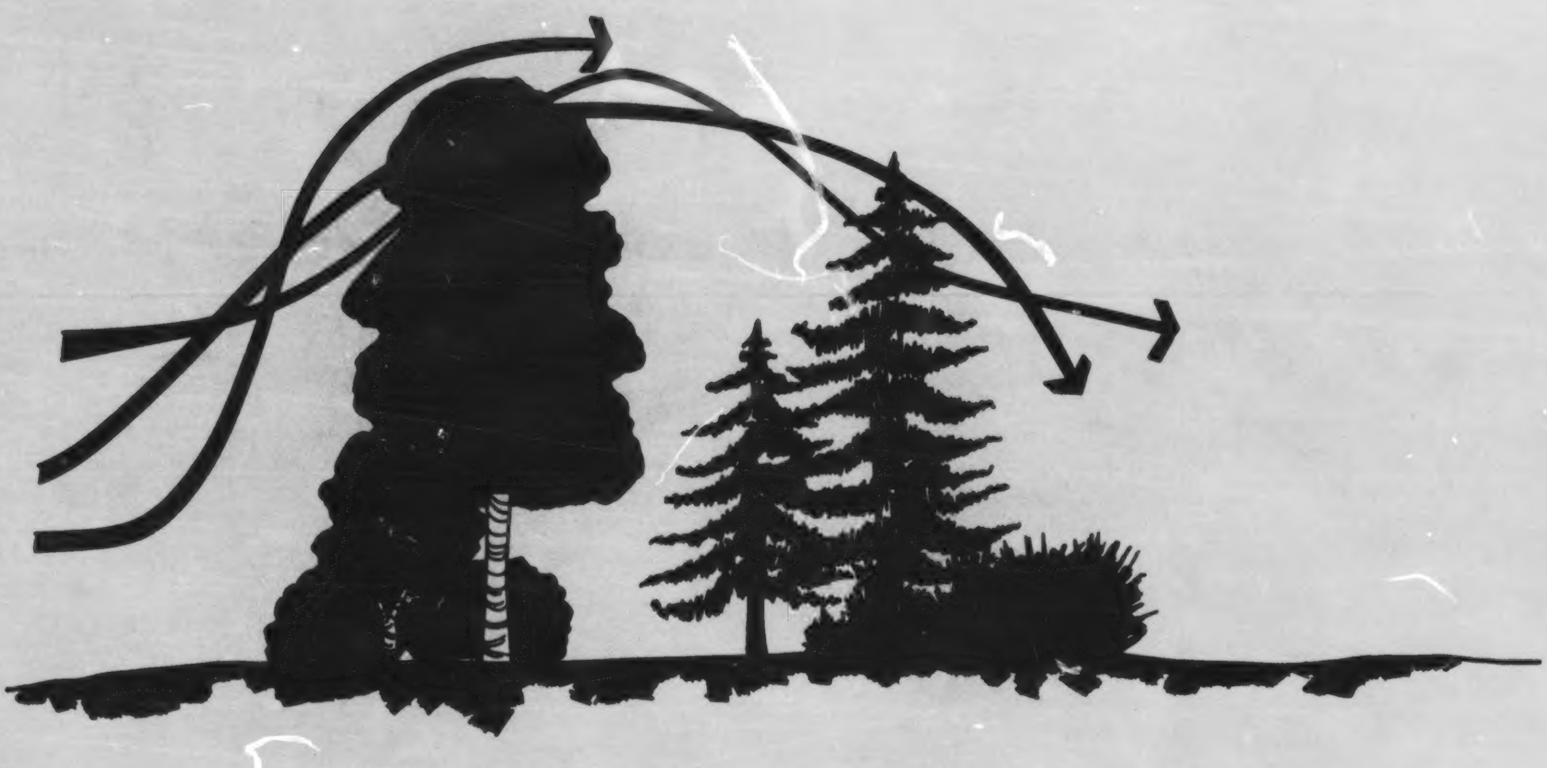


fig. II.2

complete barriers

Plant List for Energy Conservation*

PLANT	TYPE	USE
RED MAPLE	DEC. TREE	SOLAR CONTROL
SUGAR MAPLE	DEC. TREE	SOLAR CONTROL
WILLOW OAK	DEC. TREE	SOLAR CONTROL
WATER OAK	DEC. TREE	SOLAR CONTROL
PIN OAK	DEC. TREE	SOLAR CONTROL
MAGNOLIA	EVERG TREE	WIND SCREEN
HEMLOCK	EVERG TREE	WIND SCREEN
RED CEDAR	EVERG TREE	WIND SCREEN
WHITE PINE	EVERG TREE	WIND SCREEN
CHIN. HOLLY	EVERG SHRUB	WIND CONTROL
WAX MYRTLE	EVERG SHRUB	WIND CONTROL
LIGUSTRUM	EVERG SHRUB	WIND CONTROL
BOSTON IVY	DEC. VINE	SOLAR CONTROL
ENGLISH IVY	EVERG VINE	YEAR AROUND BLANKET

* The plants listed here were chosen because they are native to or grow well in North Carolina, serve the purpose of energy conservation well and are reasonably priced.

Energy Efficient Greenhouses

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greenhouse design

history

I. The greenhouse has been a reality for the last 200 years. While the idea existed for centuries, the refining of the original concept has just begun. The Twentieth Century Unabridged Dictionary defines the pre-energy greenhouse:

> greenhouse - A house, the roof and one or more sides of which consist of glazed frames, for the purpose of cultivating exotic plants, the temperature being kept up by means of artificial heat.

The true greenhouse, or hot house, was originally developed for use in the lowlands of Europe. The climate was mild and days were generally overcast. As a result, summer overheating was not a problem, and winter temperatures were moderate.

Paxton created the crystal palace for the 1851 World's Fair in Paris. The structure was a metal frame completely covered with glass. As an exhibit hall, it protected from the elements, while adding a new dimension to the concept of the greenhouse.

Shortages in conventional fuel reserves have expanded even Paxton's concept. Today man views the greenhouse as a multifaceted structure capable of heating his home, enhancing his environment and producing his food. We recognize the correlation between man and his environment, as well as the effects of the manmade environment on this relationship. By understanding the way these factors relate to one another, we can begin to design living/working spaces that take full advantage of natural systems while providing a greater variety and quality of space in terms of function and enjoyment.

problem definition

II. The first greenhouse was developed to function best under specific conditions. The structure was designed to make best use of low intensity, diffuse radiation. This design is still found in commercial greenhouses which are used throughout a variety of climatic regions. Some designs will work better in a particular area than others. In order to insure the success of your system, fully define the criteria which the design must fulfill.

PROBLEM DEFINITION = NEEDS & REQUIREMENTS
+CONSTRAINTS
+RESOURCES

CONSTRAINTS = TIME
+MONEY
+THE SITE

RESOURCES = NATURAL RESOURCES + MANMADE ASSETS

NATURAL RESOURCES
1)Landforms
2)Soils
3)Vegetation
4)Natural Energies
5)Site Location

MANMADE ASSETS
1)Existing Structures & Drainage Ways
2)Roads & Access Ways

PRACTICAL QUESTIONS

1) What needs and requirements must the design fulfill?

2) Is there a priority of needs?

3) Are some needs more important than others?

4) What are the conditions under which the structure must function?

5) What are the constraints of the problem?

6) What resources are available to work with?

problem solving

III. The elements of a greenhouse system are interrelated in such a way that making changes in only one part of the system can cause all the others to be altered.

As you analyze the natural systems, the relationships will become more clear. "Trade offs" (give and take between needs and practicality, or needs and importance) will begin to surface. This prefaces a part of a decision making process which can become futile unless goals are established early and followed throughout.

The sun and wind are elements acting upon and responding to landforms, vegetation and the built environment ("built environment" refers to manmade structures, including architecture). Consequently, by manipulating these components, the designer can alter the natural forces to better suit the established needs throughout the seasons.

orientation

IV. Orientation to the site is extremely important. As the greenhouse concept is based on interaction with the sun, it is essential for the structure to have access to available solar energy.

A true solar south orientation(see page of the Core Course for explanation of true solar north and south) will allow the greatest possible amount of sunlight to penetrate. (See Figure 4.0).

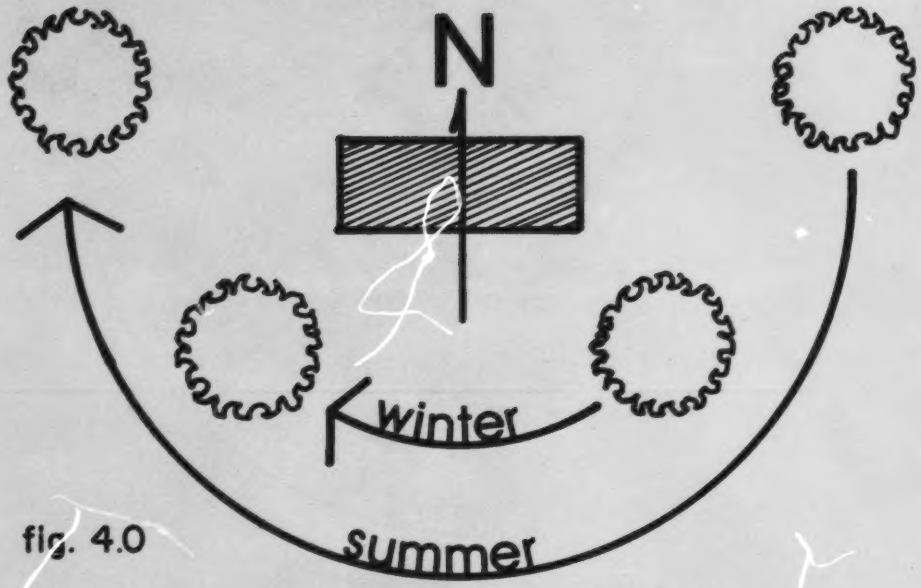

N
winter
summer

fig. 4.0

maximum solar gain efficiency

Buildings not facing the south will receive less sun. (See Figure 4.1).

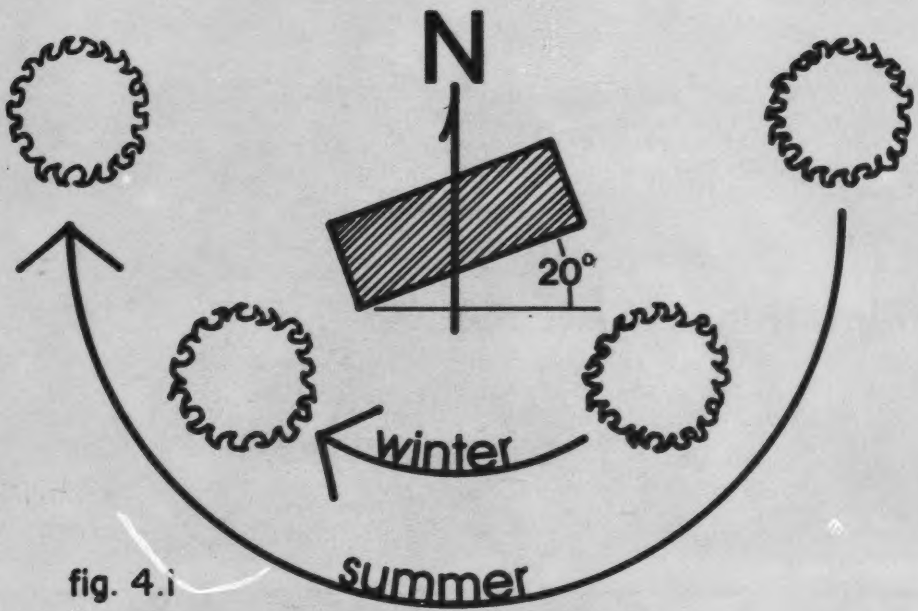

N
20°
winter
summer

fig. 4.i

95% solar gain efficiency

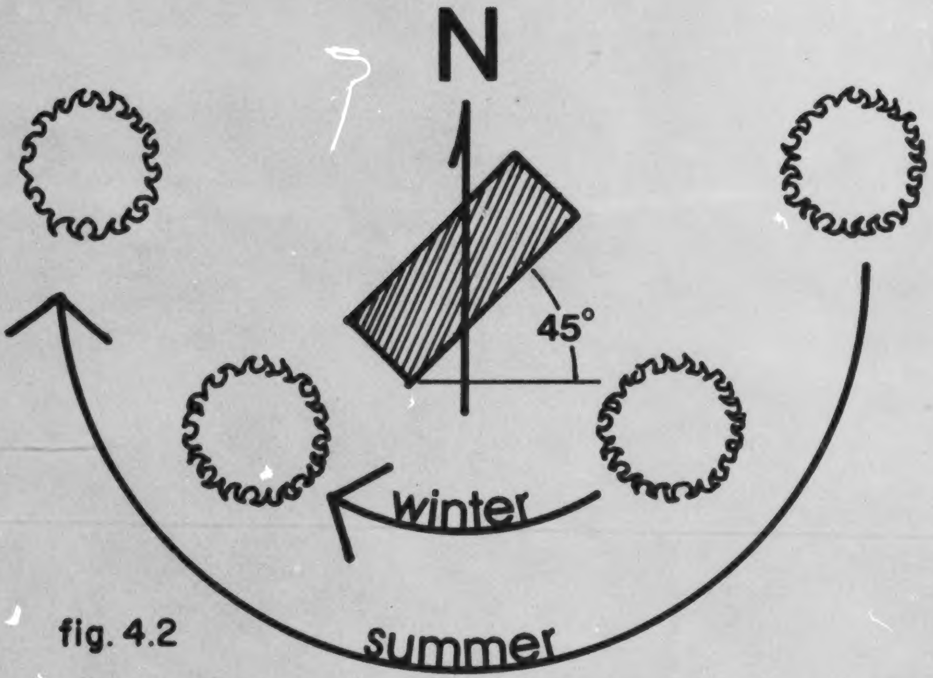


fig. 4.2

80% solar gain efficiency

When speaking of the attached greenhouse, orientation becomes more complex. The structure to which the hothouse is attached should shelter it from cold northern winds without obstructing transmission of the sun's rays. The optimum position for the proposed greenhouse must be determined by the orientation of the existing structure to which it will be attached. (See Figure 4.3).

True South Facing House (See Figure 4.3).

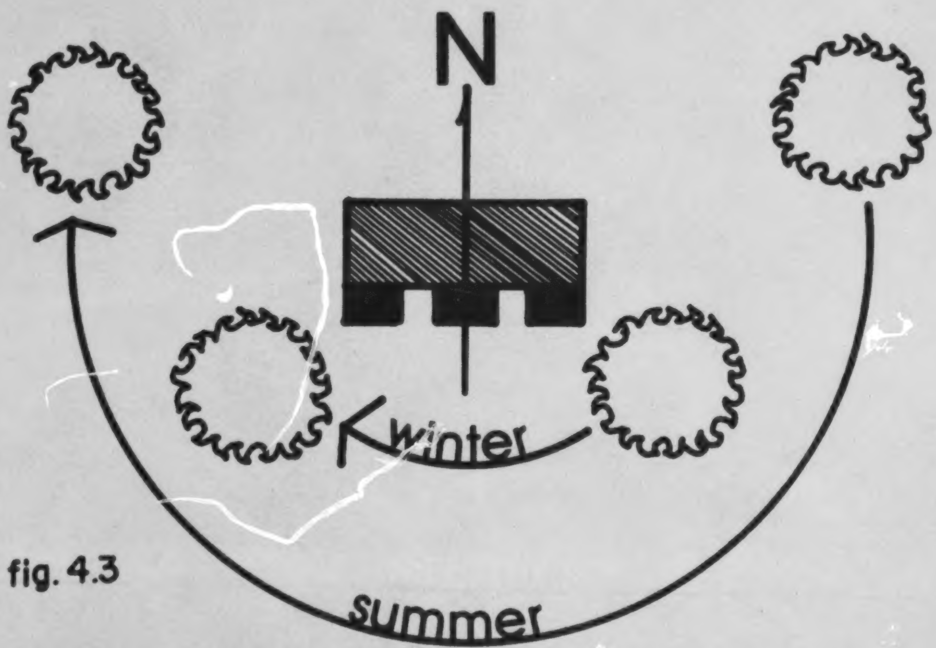


fig. 4.3

On a true south facing house, the greenhouse may be located on any portion of the south wall.

- Less than 45 East of South (See Figure 4.4).

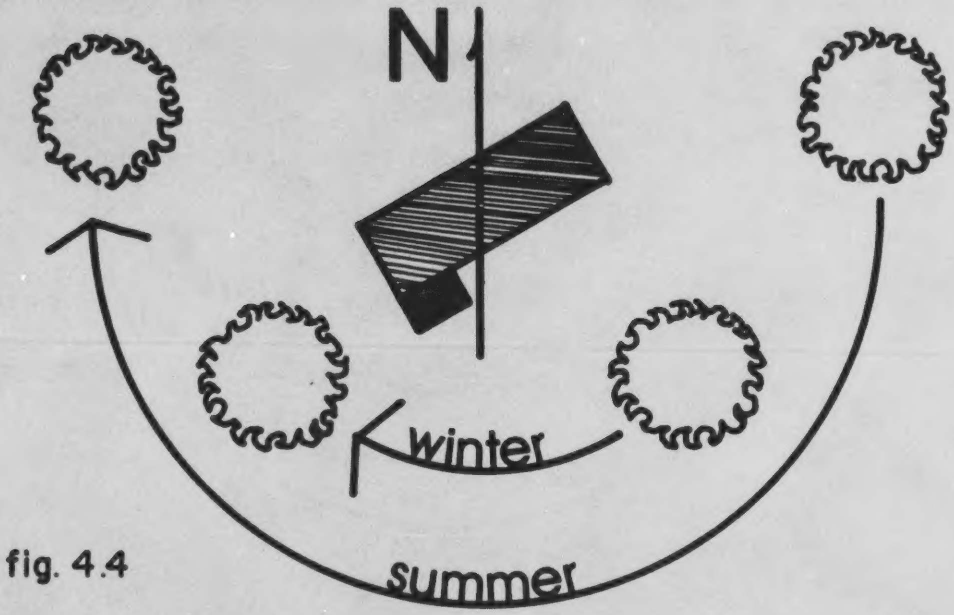

N
winter
summer

fig. 4.4

- 45° east of south (See Figure 4.5).

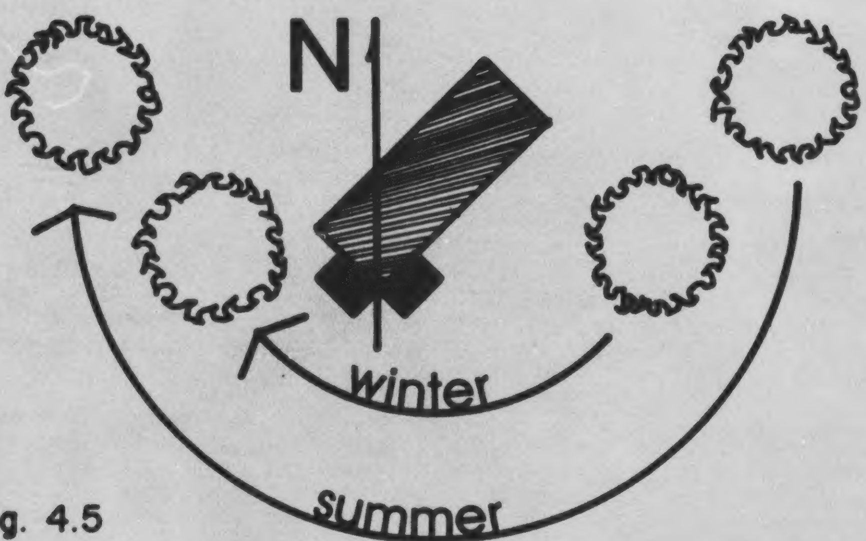

N
winter
summer

fig. 4.5

Greater than 45 East of South (See Figure 4.6).

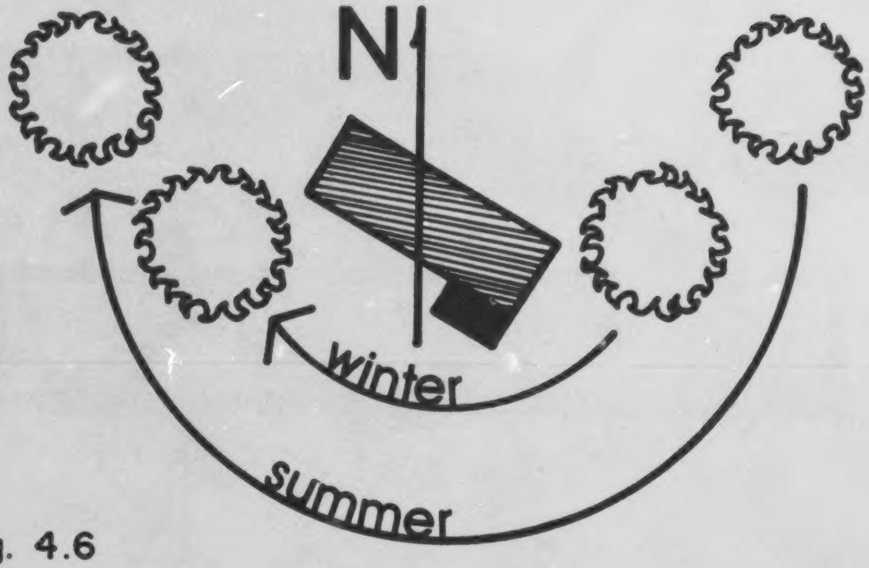


fig. 4.6

the greenhouse

V. In order to maintain a specific temperature range, heat must be added in winter and taken away during summer. The alternative ways of heating and cooling can be generally classified into the categories of active systems and passive systems.

Today most all permanent greenhouses are equipped with features which help to maintain a consistent temperature and humidity. The way in which the system accomplishes this will determine whether it is active, passive, or a blend of the two.

Lying in the sun would be a passive example of tanning, while a sun lamp would represent the active system. Both achieve the same effect. Active systems, however, require the expenditure of additional energy. What does this additional energy buy? It purchases the convenience of tanning at night, on a cloudy day, etc.

Generally speaking, active systems are convenient to operate. Circulating fans and pumps can be switched on or off to maintain a constant temperature. Passive systems require some advance planning, as well as a working knowledge of the system, in order to function properly. Well designed passive systems "turn on" and "shut off" throughout the seasons in response to the earth's natural systems.

the greenhouse shape

VI. Efficiency begins with the greenhouse shell itself. Certain sizes and shapes will preform better than others.

In terms of energy efficiency two factors are affected by building configuration.

Solar Heat Gain
+Thermal Efficiency
=Energy Efficiency

The key to controlling these factors lies in the size of the surface areas and their orientation to the sun. (See Figures 6.0 & 6.1).

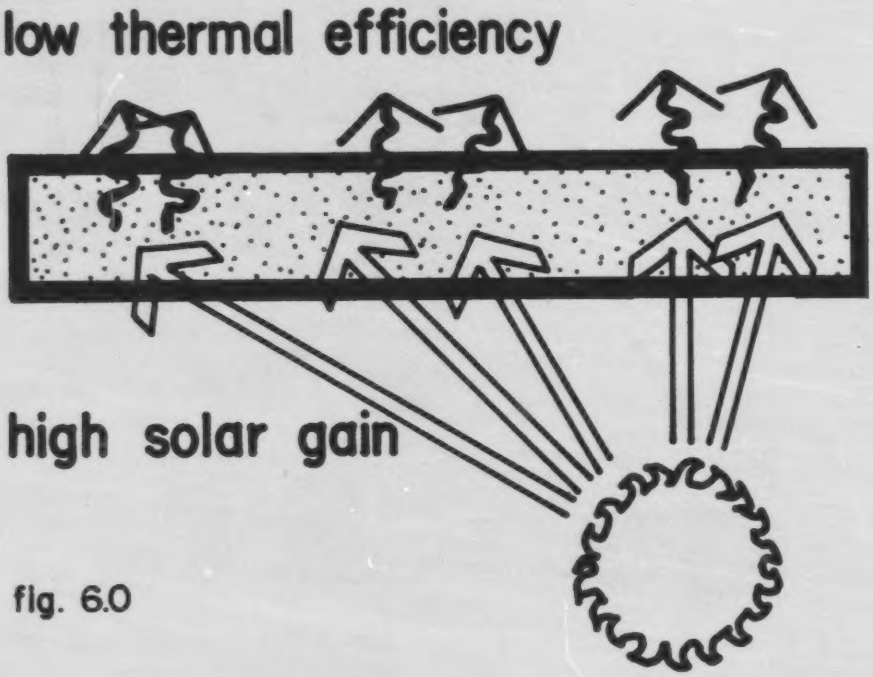

low thermal efficiency
high solar gain

fig. 6.0

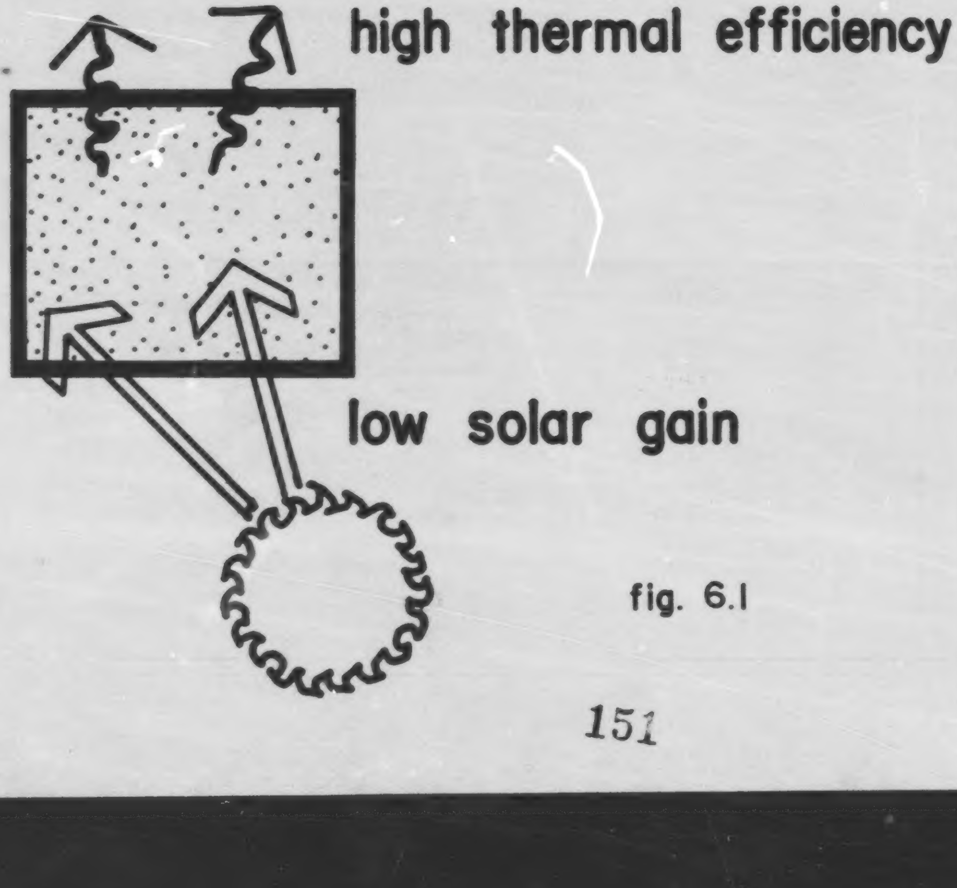

high thermal efficiency
low solar gain

fig. 6.1

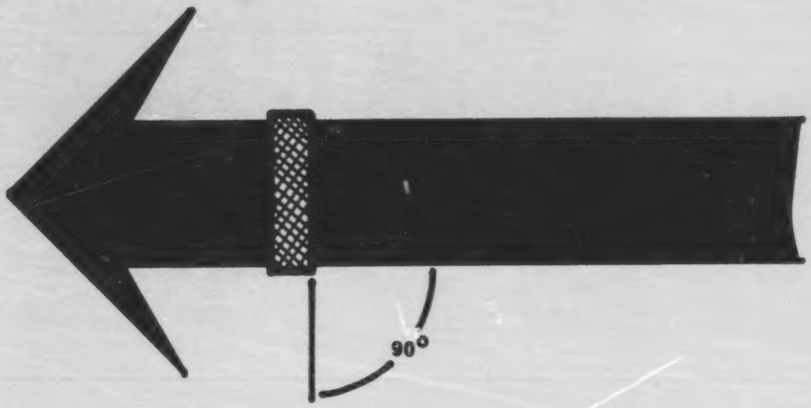
Another factor of configuration which affects the efficiency of the greenhouse is the slope of the south and north walls.

The slope of the south wall is critical to solar gain.

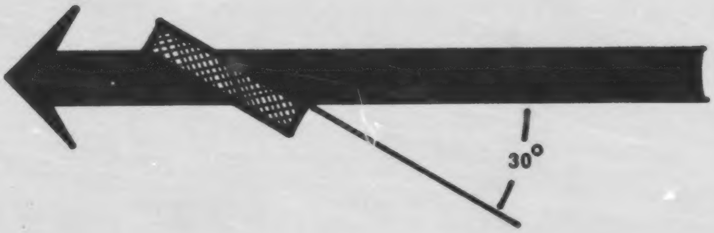
The slope of the north wall is critical to the thermal efficiency of the building.

The amount of solar radiation passing through a glazing system will depend upon the angle at which sunlight strikes the surface.

The sun's rays, for all intents and purposes, are parallel beams of light. Rays striking a perpendicular surface impart the greatest possible amount of energy to that surface. A change in the angle will result in less energy falling on that surface.(See Figures 6.2 & 6.3).



perpendicular rays fig. 6.2



oblique rays fig. 6.3

The angle at which a beam of light strikes a given surface is called the angle of incidence. If all light is not absorbed by the surface, then there will be a certain degree of reflectance. The angle of reflection will be equal to the angle of incidence. (See Figure 6.4).

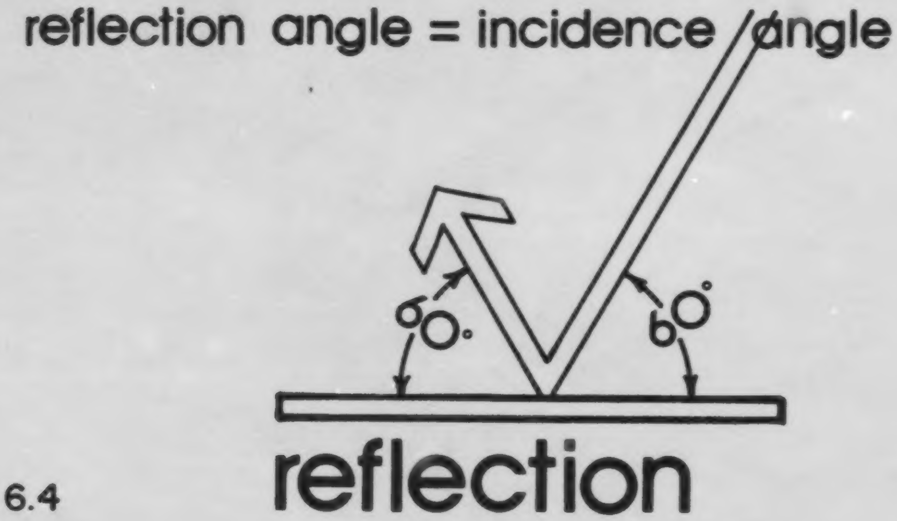


fig. 6.4

South wall and/or roof angles should be oriented so that light strikes at or near a 90 degree angle of incidence during winter months.

For example, at latitude 36° the average height of the sun during the harsh months of December, January, and February is approximately 35°. Since we know that light striking a surface at 90° imparts the greatest amount of energy, the south roof angle should complement the sun's angle so as to maximize solar gain. In this particular instance:

90° ideal angle of incidence
-35° solar angle
=55° south side angle

Increasing or decreasing this angle would shift the maximum optimization of solar gain to another set of months. While a 55 degree south angle would be optimum for 36 degrees north latitude, a variation may be necessary due to construction limits or materials availability. (See Figure 6.5).

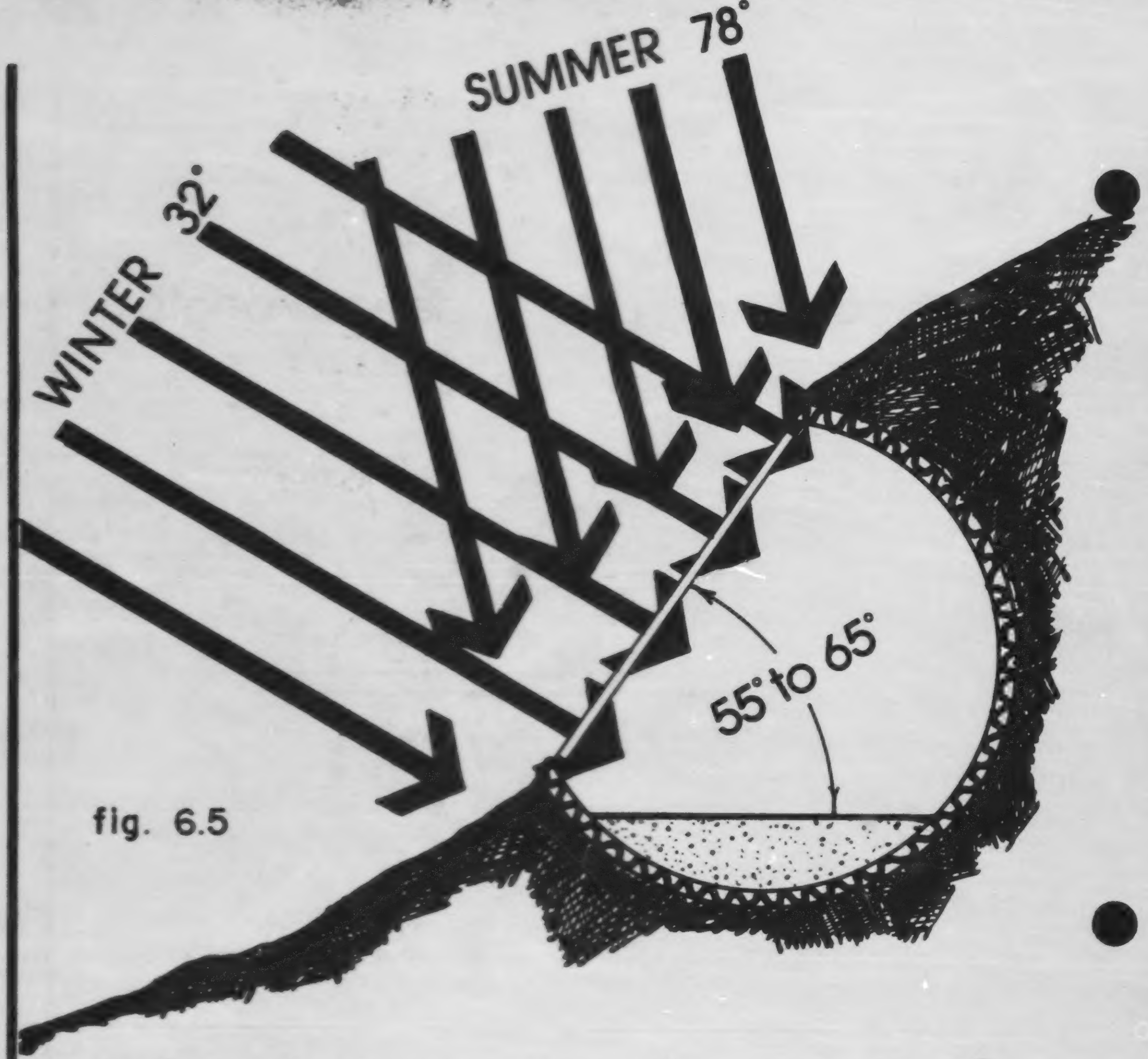


fig. 6.5

glazing angles 36°

commercial designs

VII. Commercial designs can be discussed and evaluated at this point based on information previously discussed. Working systems for heating and cooling will be dealt with later in this division. Criteria for evaluation of basic designs will be as follows:

SIZE: Most commercial designs are based on a modular system. This allows a greater degree of flexibility in the sizing of a greenhouse. Modular systems can allow expansion along the length and/or width of a standard design.

a. Fixed size - Definite size restrictions by design
b. Modular - Flexible size by additions to design

SPATIAL EFFICIENCY: Refers to percentage of usable space. Radically sloped walls, columns and braces are negative elements in terms of spatial efficiency.

INSULATION: Pertains to glazing possibilities(number of layers)

a. single glazing
b. double glazing
c. triple glazing

GLAZING MATERIALS: a. plastic
b. fiberglass
c. glass

SOLAR EFFICIENCY: Slope of walls and building configuration determine the structures ability to accept and hold heat.

(See Figures 7.1, 7.2, 7.3, 7.4, 7.5, 7.6, & 7.7)

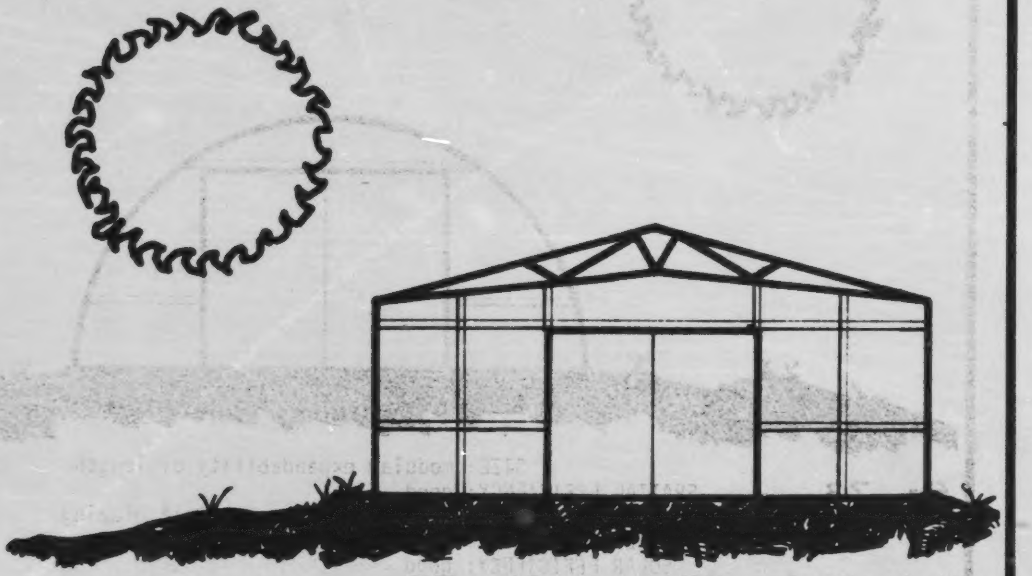


fig. 7.1

SIZE: modular expandability in length and width
SPATIAL EFFICIENCY: excellent
INSULATION: single or double glazing
GLAZING MATERIAL: glass or fiberglass
SOLAR EFFICIENCY: fair

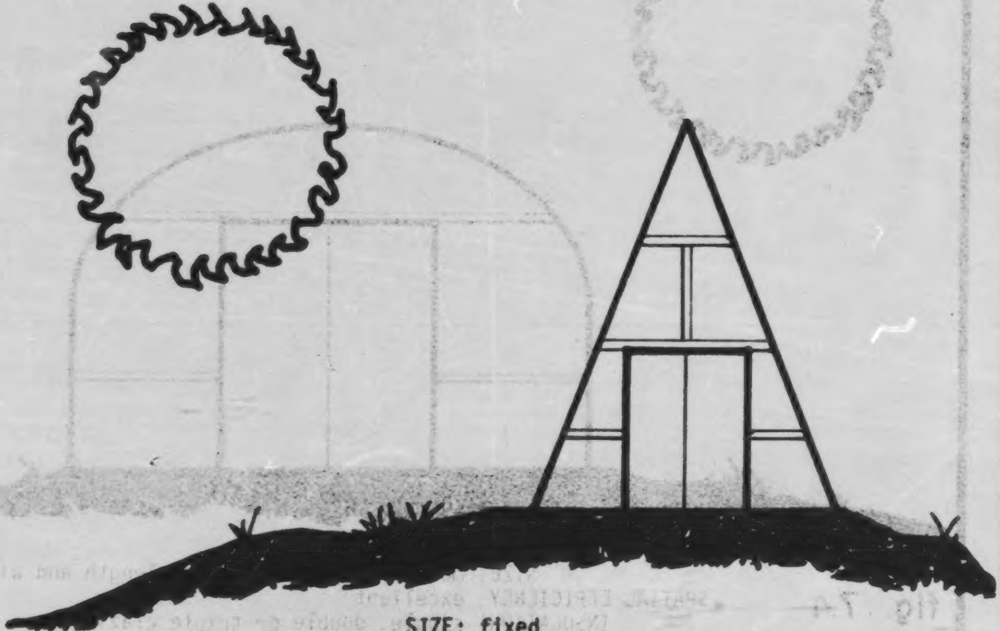


fig. 7.2

SIZE: fixed
SPATIAL EFFICIENCY: fair
INSULATION: single or double glazing
GLAZING MATERIAL: glass or fiberglass
SOLAR EFFICIENCY: excellent

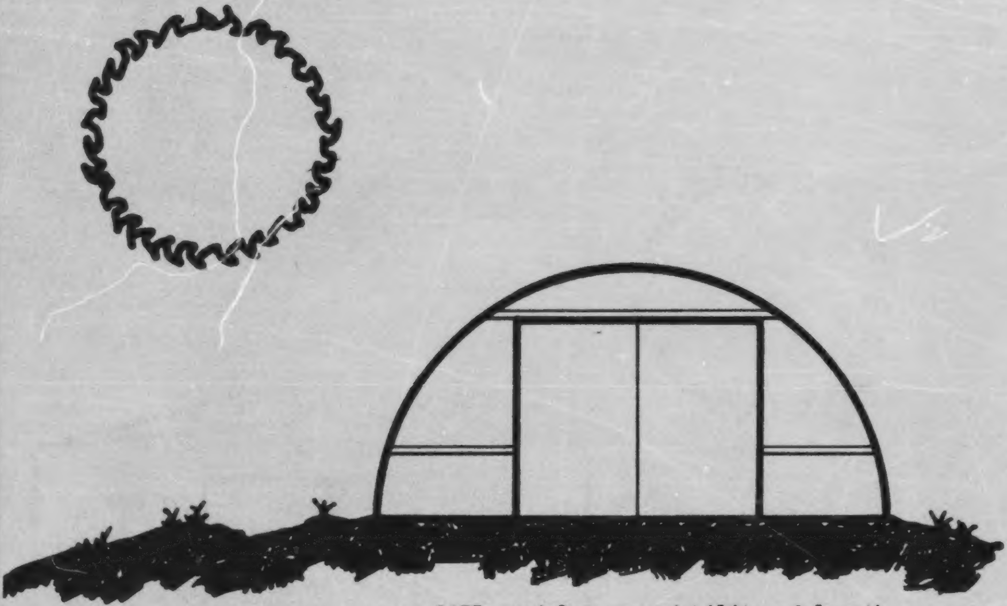


fig. 7.3

SIZE: modular expandability of length
SPATIAL EFFICIENCY: good
INSULATION: single, double or triple glazing
GLAZING MATERIAL: fiberglass or plastic
SOLAR EFFICIENCY: good

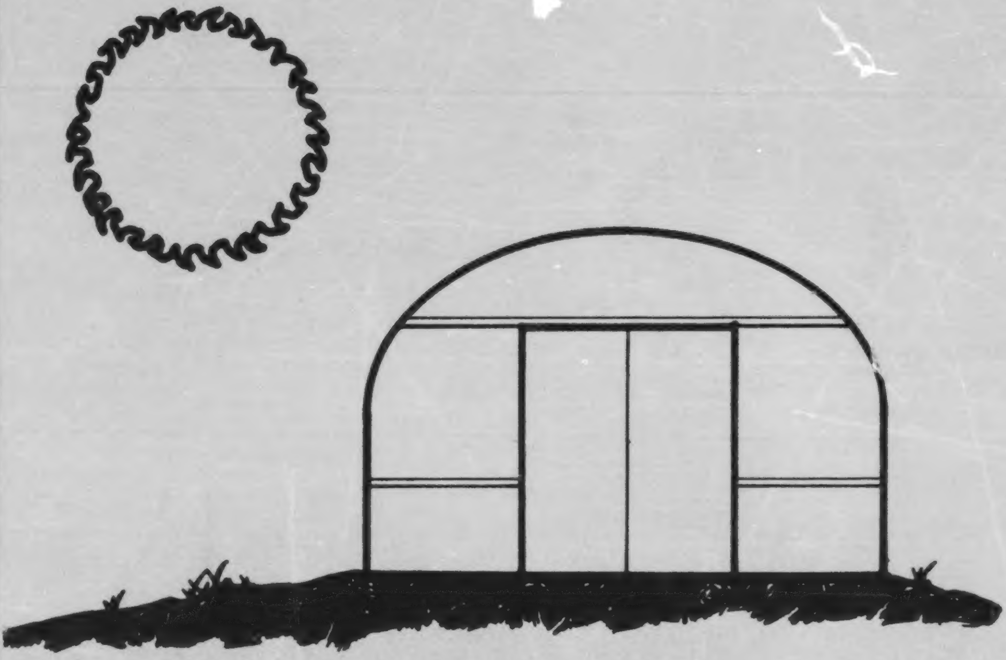


fig. 7.4

SIZE: modular expandability of length and width
SPATIAL EFFICIENCY: excellent
INSULATION: single, double or triple glazing
GLAZING MATERIAL: fiberglass or plastic
SOLAR EFFICIENCY: good

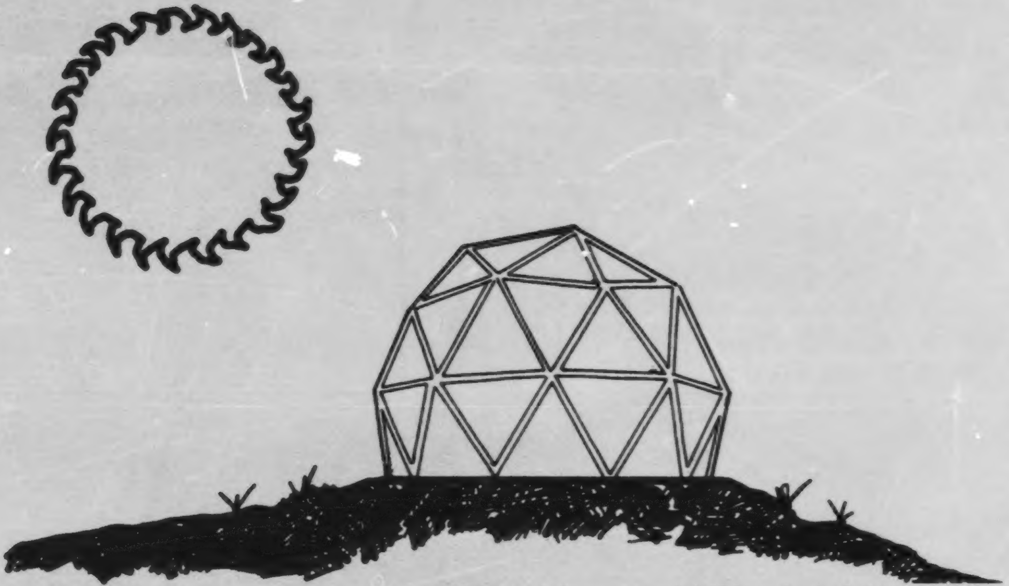


fig. 7.5

SIZE: modular expandability in height and diam.
SPATIAL EFFICIENCY: good
INSULATION: single or double glazing
GLAZING MATERIAL: glass or fiberglass
SOLAR EFFICIENCY: fair

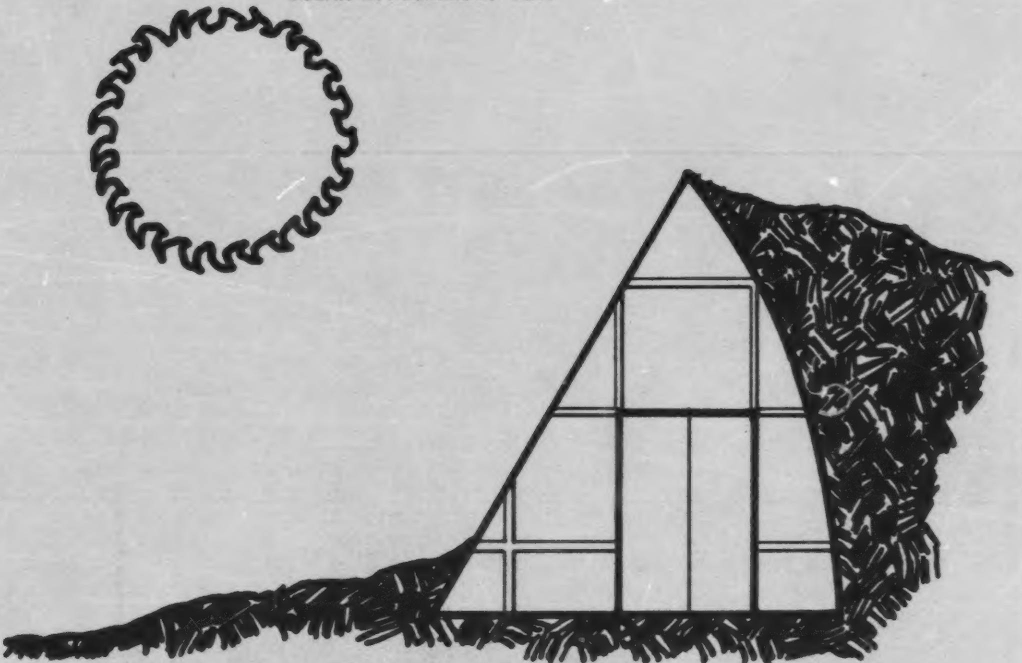


fig. 7.6

SIZE: fixed
SPATIAL EFFICIENCY: fair to good
INSULATION: single, double or triple glazing
GLAZING MATERIAL: glass, fiberglass or plastic
SOLAR EFFICIENCY: excellent

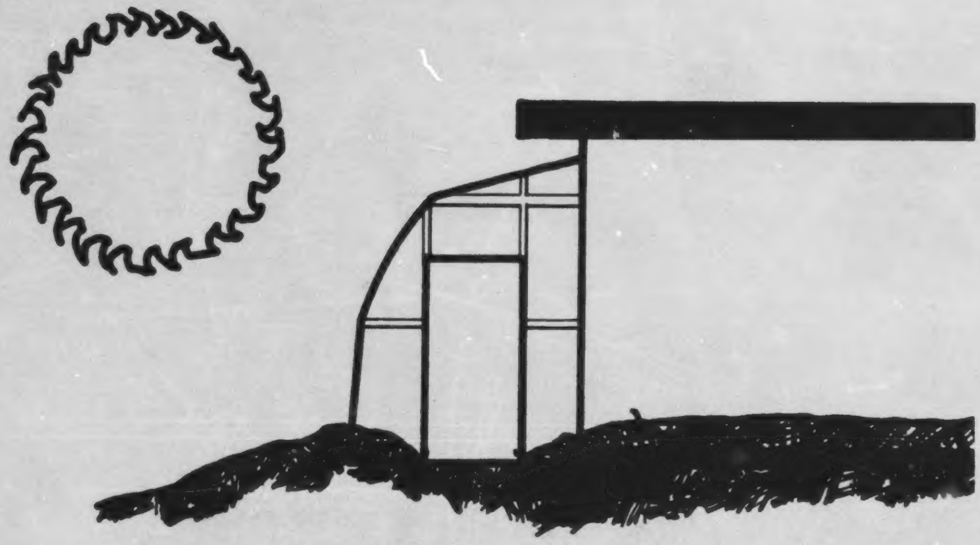


fig. 7.7

SIZE: fixed by dwelling size
SPATIAL EFFICIENCY: good
INSULATION: single, double or triple glazing
GLAZING MATERIAL: glass, fiberglass or plastic
SOLAR EFFICIENCY: excellent(given proper orientation to existing structure)

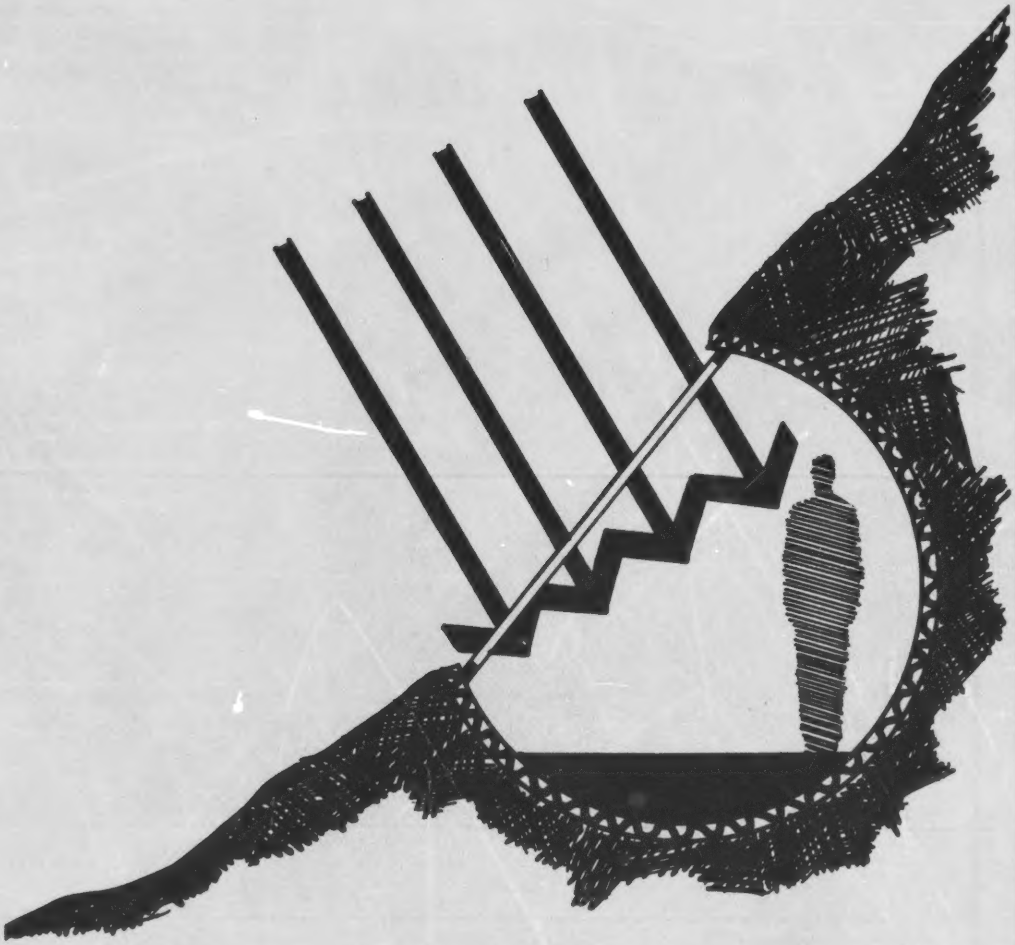
systems

VIII. Siting and greenhouse structure and configuration have been examined in reference to winter heating requirements. The next step involves the details of greenhouse design in relationship to a heating and cooling system. Specifically systems that utilize passive solar design will be examined.

The three basic approaches to passive solar heat collection and storage are as follows:

1. Direct Gain
2. Indirect Gain
3. Isolated Gain

Direct gain is present in any structure where sunlight penetrates to the interior. The interior space is directly heated by the sunlight. Sometimes a thermal mass is added to absorb and retain some of the heat gain. Glazing area, material and colors will decide the performance of the system. Trees, curtains, shutters, etc. are effective controls for regulating heat gain. (See Figure 8.0).



direct gain fig. 8.0

Indirect systems are placed between the sun and interior spaces. The sun directly heats a storage mass, which in turn gives off(transmits) heat to the interior.

In order to "turn on" or "shut off" an indirect gain system, the energy must be interrupted before it is transmitted to the mass. Deciduous trees, curtains and shutters are applicable control devices.(See Figure 8.1).

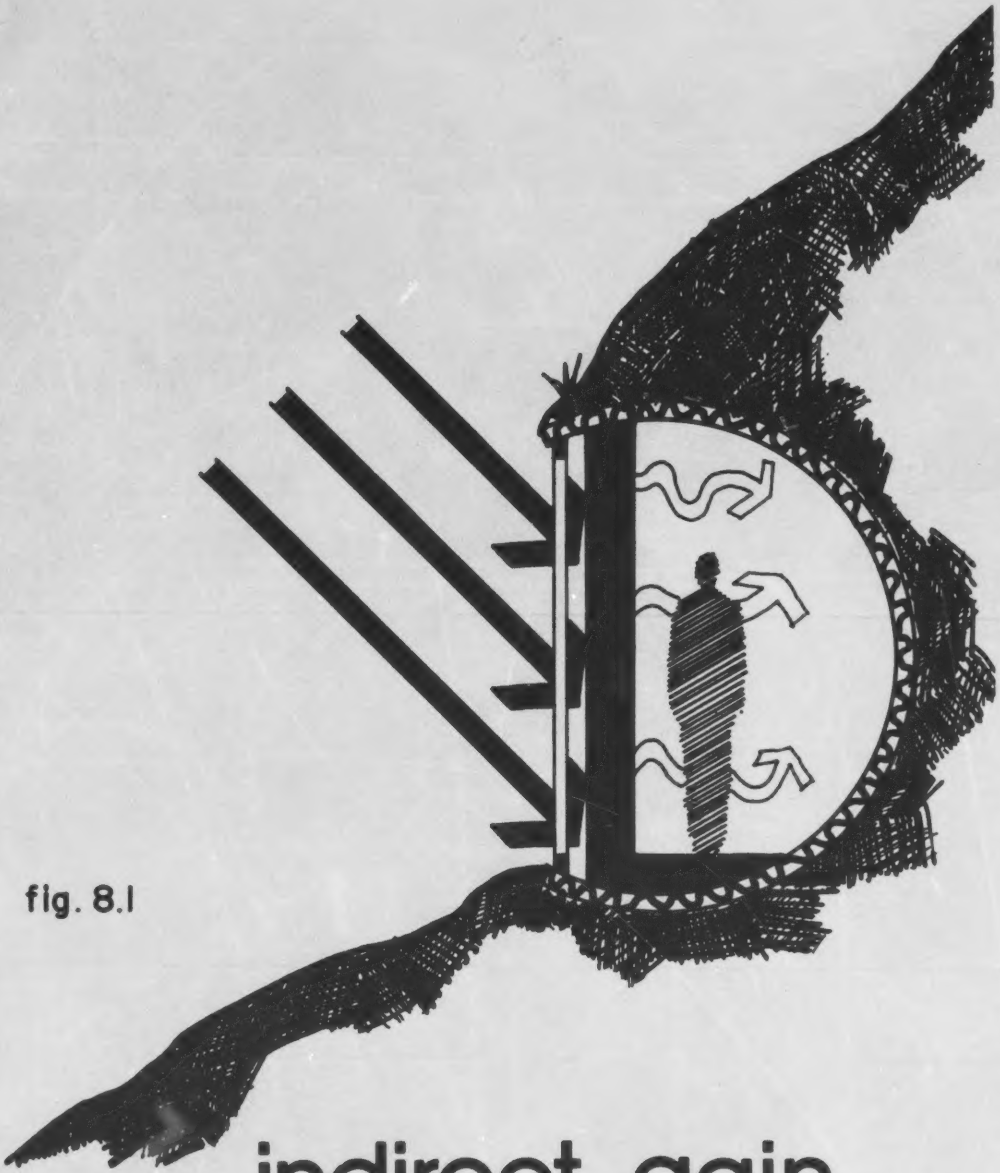


fig. 8.1

indirect gain

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Isolated systems are detached from the structure. Sunlight can fall on an isolated system, but unless the heat is allowed to circulate to storage areas or to distribution points, the system will impart no energy to the interior of the structure. Valves and dampers are most commonly used as control devices. (See Figure 8.2).

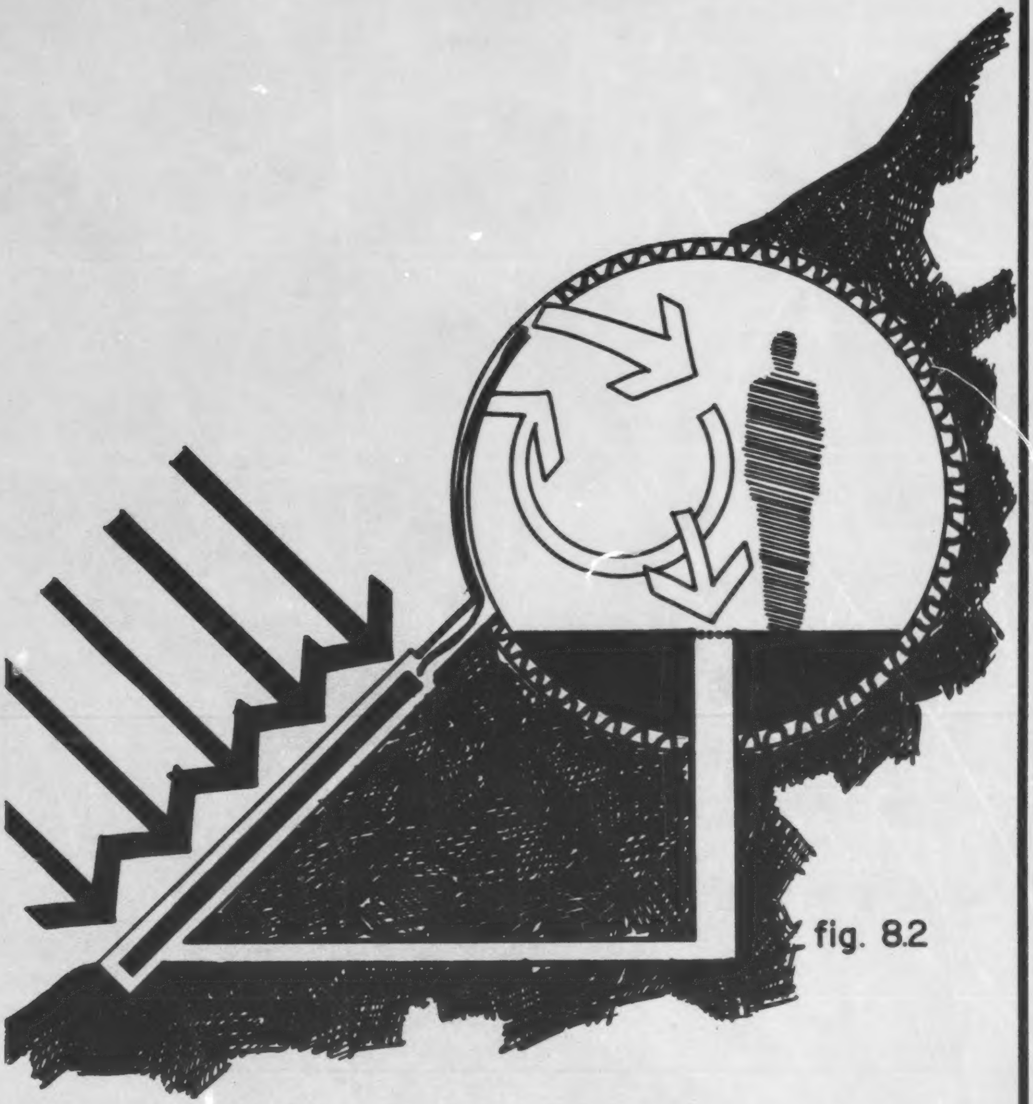
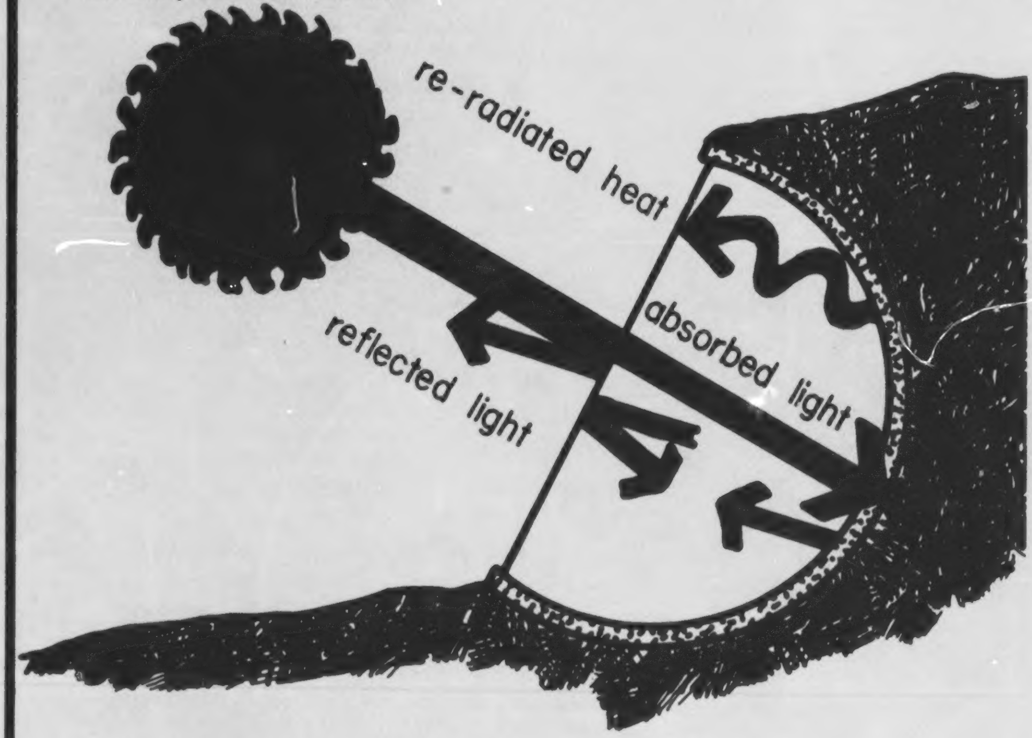


fig. 8.2

isolated gain

heat gain

These three approaches to passive solar design will be utilized in analyzing and discussing the elements of a heating and cooling system for a greenhouse. The elements of the system are heat storage/distribution, insulation/shading devices, and ventilation.



greenhouse effect

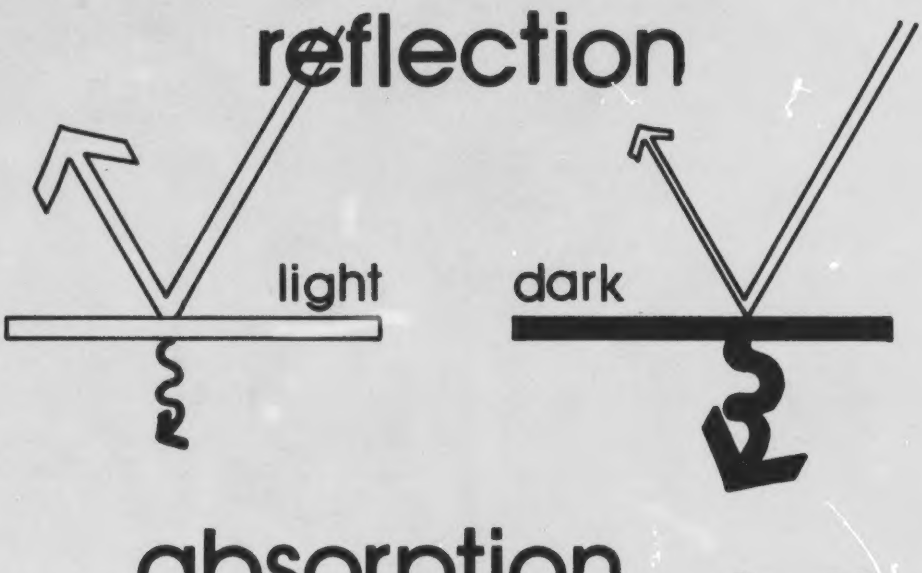
heat storage/distribution

A. A six-inch wall will absorb the same amount of heat as a fifteen-inch wall.

The difference between the two is time. The heat will pass quickly through six inches of masonry, while it would take considerably longer for the heat to travel through a fifteen-inch masonry wall. The wall should be thick enough to time the passage of the heat through the wall so that the heat begins to be released from the interior side of the wall during the cooler hours of afternoon and night.

Factors controlling the performance of thermal storage walls are:

1. Color. Dark colors absorb; light colors reflect. Use wall color to fine-tune wall needs. For instance, if the wall is now black, and the greenhouse is overheating, paint the wall a lighter shade. (See Figure 8.3).

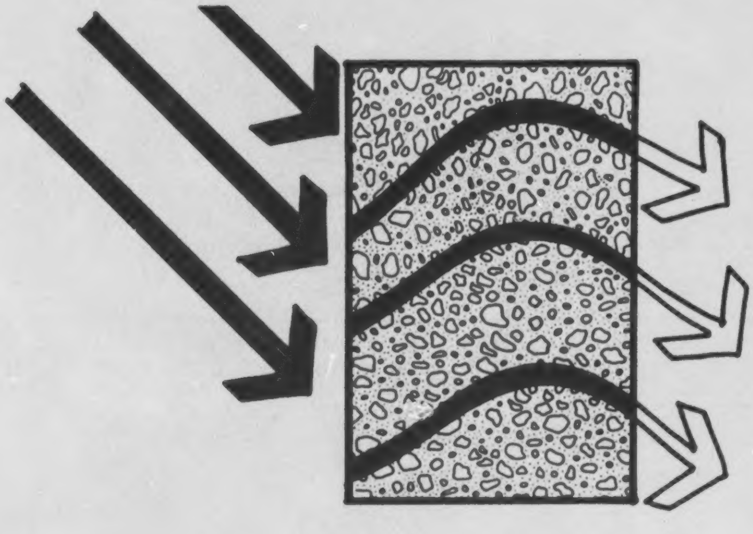


absorption fig. 8.3

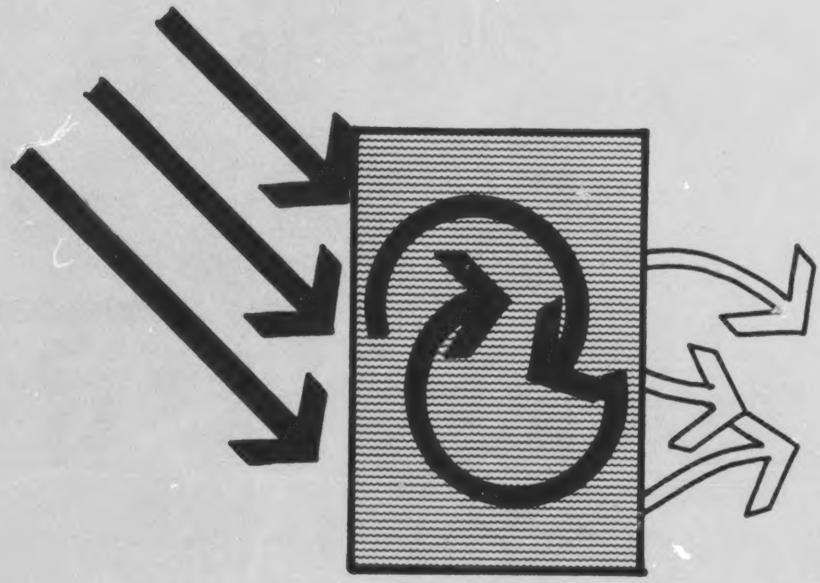
2. Materials. The thickness of a thermal storage wall will be determined by the material used to construct the wall. Sizing based on material selection.

Water	6"
Brick	12"
Concrete	16"
Rock	3-10 feet

(See Figures 8.4 & 8.5).



masonary wall fig. 8.4



water wall

fig. 8.5

3. Size of thermal storage wall is determined by floor area to be heated.

Average Winter Outdoor Temp.	% of sq. ft. of floor area	
	Masonry	Water
15	.85	.75
20	.75	.65
25	.70	.55
30	.60	.45
35	.45	.35
40	.35	.25
45	.30	.20

For example: for a 100 sq. ft. greenhouse in a climate with an average winter outdoor temperature of 15 degrees, the thermal storage wall must be 85 sq. ft. for masonry and 75 sq. ft. for water.

If the storage wall is a water type, translucent glazing is not necessary since the natural convection currents of fluids will distribute heat evenly across the length of the wall. Only in instances where the water wall consists of masses of individual containers (jugs or drums), in a stacked fashion, will a water wall function better with a translucent glazing.

In instances where a masonry storage wall is located behind a double glazed wall, it may be advantageous to use a translucent glazing. Sunlight would pass directly through the first layer of transparent glazing. Upon striking the second translucent layer, the light rays would disperse. This diffused light would allow the masonry wall to absorb heat evenly, thus eliminating cold spots.

Once heat has been stored, a method of distribution must be created in order to keep the structure within the comfort zone at night.

The simple way to redistribute heat is to place the storage system so that radiant heat will be passively released. An example would be a masonry floor or wall which, after directly absorbing sunlight during the day, would simply re-radiate the stored heat through natural thermodynamic principles. A modification of this concept involves the placement of vents along the top and bottom perimeters of the masonry wall. Cool air is drawn in from the floor, heated as it contacts the masonry, and carried out through the top vents. This convection loop will distribute heat to a greater portion of the structure than will a simple masonry wall.(See Figures 8.6 & 8.7)

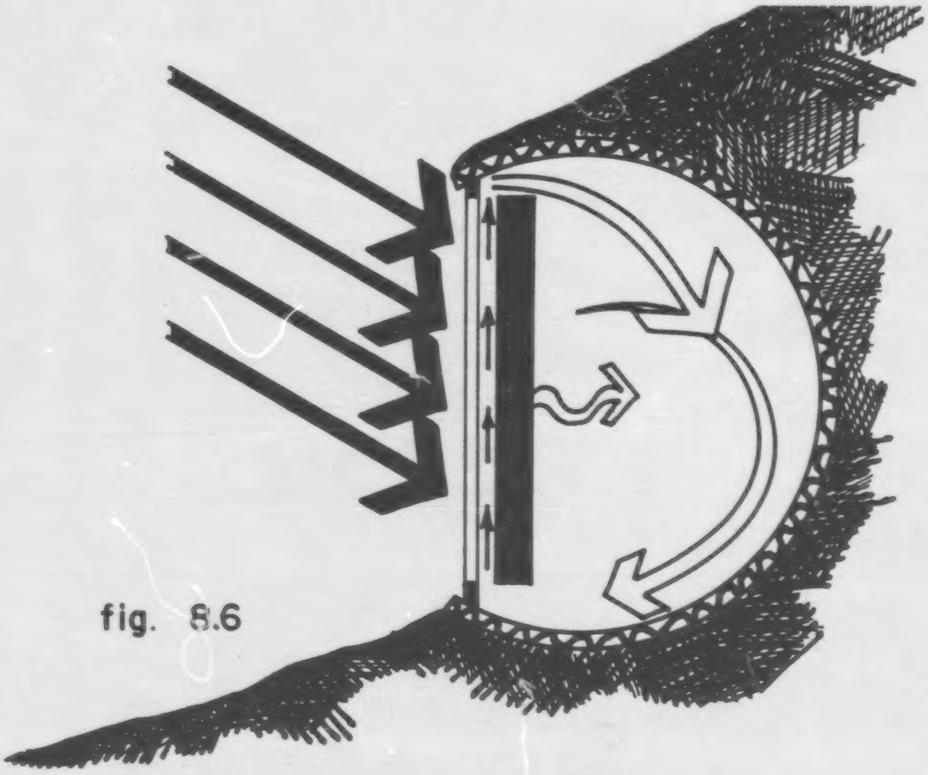
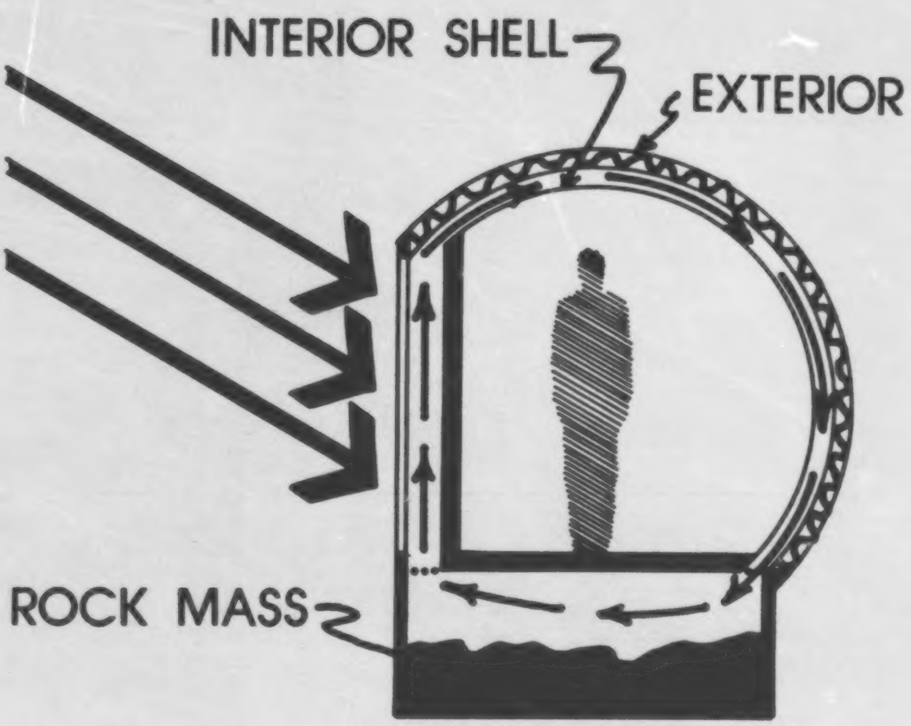


fig. 8.6

trombe wall

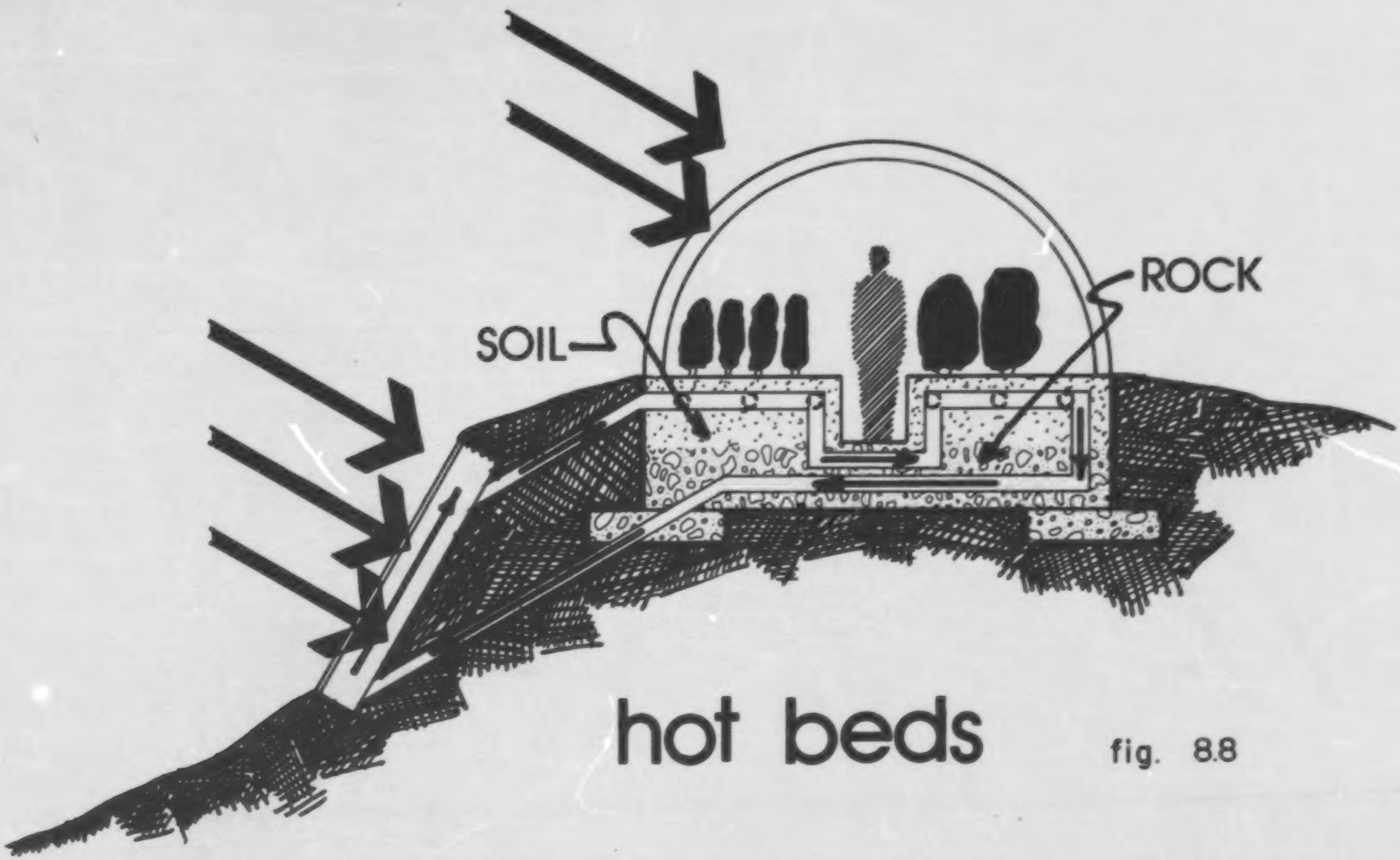


solar envelope fig. 8.7

In some areas where the cloudiness index obstructs solar gain for days at a time, it might be advantageous to connect a wood/coal burning stove to the system. The auxiliary heater would supplement the system on overcast days, as well as add extra energy for use when exceptionally cold nights are anticipated.

In a structure where the sole concern is the growing of plant materials, the main object is to heat the plant. Heating the air within is the least effective method as hot air will migrate upward leaving cooler air surrounding the plants.

For plants, heating the beds directly will cause the least amount of heat loss. This concept will involve the placement of heating pipes or a single rock layer beneath the plant bed. Stored heat in the form of hot air can be channeled beneath the planting. Heat beneath the bed will gradually move upward effectively maintaining a safe temperature by warming the plant directly instead of the air surrounding it. Essentially, this method of "hot beds" creates another microclimate within the already existing greenhouse climate. (See Figure 8.8)



hot beds fig. 8.8

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insulation

B. Insulation is required to maintain any temperature difference between exterior and interior environments. The configuration of the structure and the type of insulation used will largely determine the thermal efficiency of the greenhouse.

insulation for heat retention

A well-insulated structure is essential for efficient use of stored heat.

Vegetation, as an insulating material against wind, has been discussed at length in the Landscaping for Conservation Section.

Berms (earth piled into mounds) can be used to cut down on heat loss through the north, east, and west faces of the structure. Since the south face is the main access to solar gain in the winter, it should be left open to sunlight. Berms protect from north winds primarily, so the north-facing side of the hot house should be as completely covered as possible. Adequate drainage will be required in some instances to prevent seepage into the structure itself. Wet soil is a poor insulator. Drainage will keep the berm dry, thus allowing it to protect the interior space better. Rock mulch and vegetation should be used to stabilize berms and steep slopes from erosion. (See Figure 8.9)

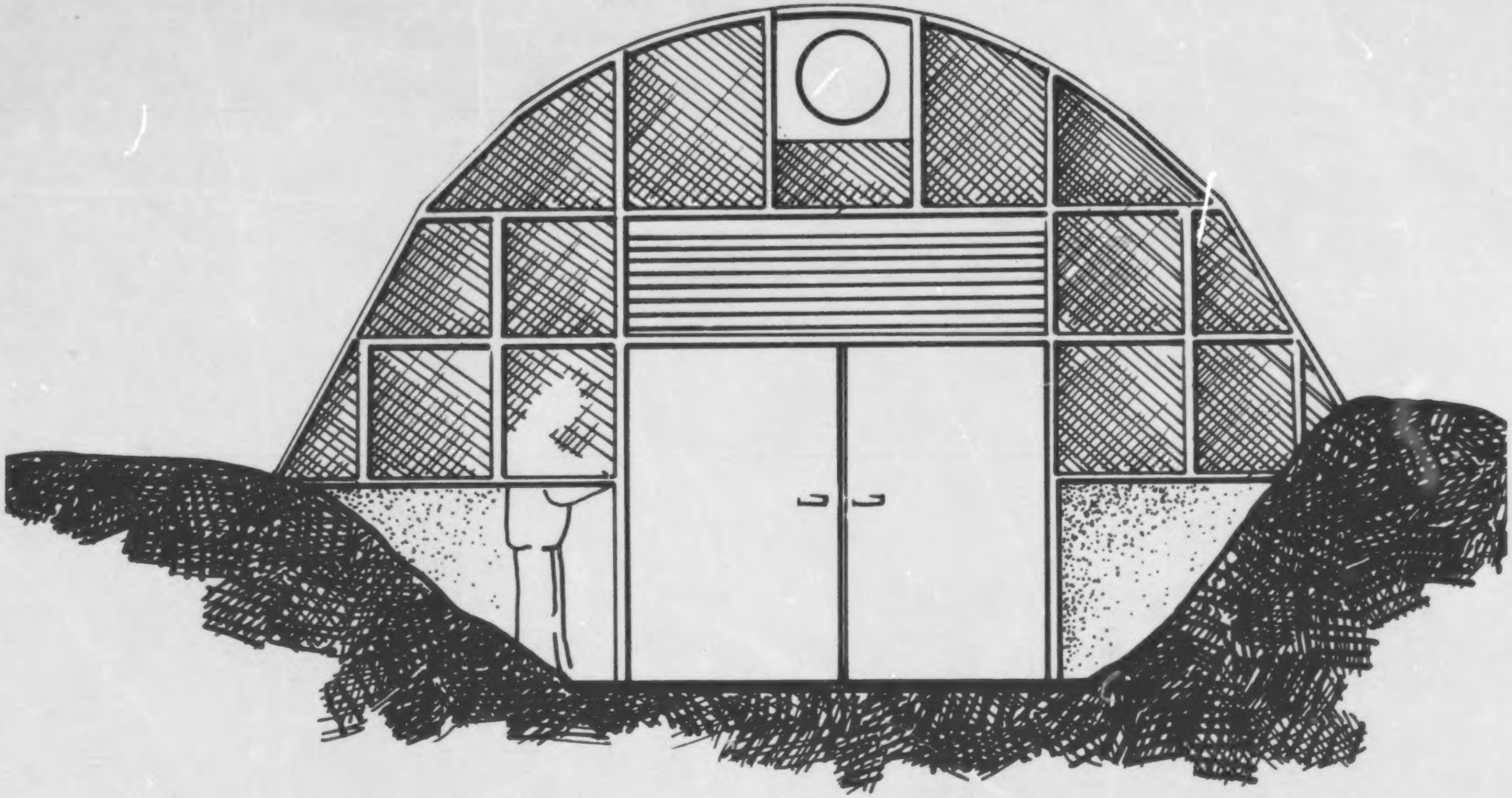


fig. 8.9

berms

The depth to which the structure is set into the ground can help maintain a safe termperature range. A structure below or close to the frost line (plane beneath the top soil, below which no freezing occurs) will conserve more energy than one constructed with slab on grade (foundation flush with ground level).(See Figure 8.10).

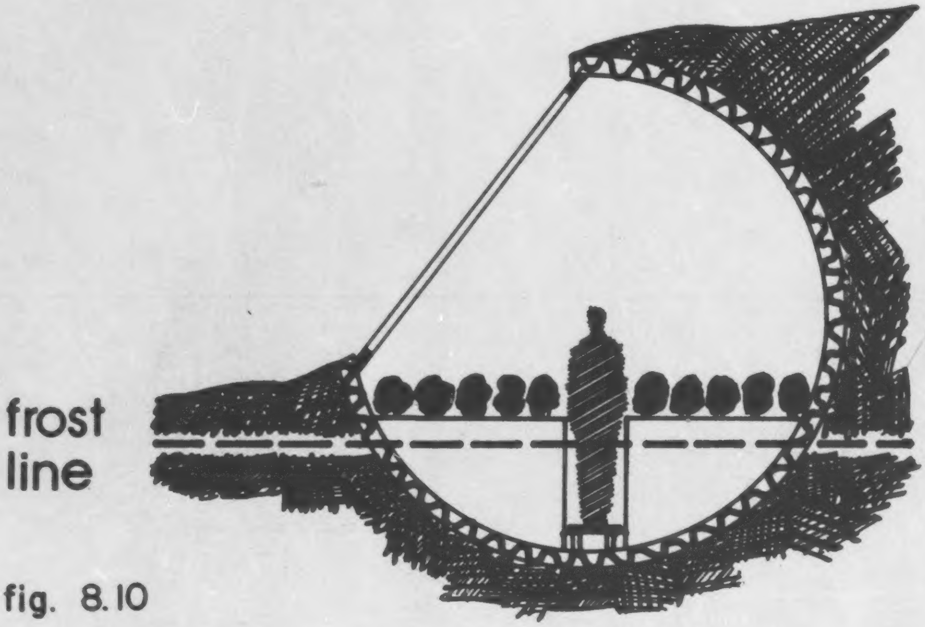


fig. 8.10

The vestibule concept, when used in major entrances, acts as a buffer zone between the environment and the greenhouse microclimate. Vestibules should be well insulated within themselves with all joints and gaps sealed with weather strip or caulking. For commercial use, vestible and vestibule doors should accept trucks and other transport vehicles so that maintenance of plants in winter can take place without excessive heat loss. The vestibule can also be used as a storage area for frequently-needed materials.

The alternative to an add-on vestibule would be simply to block off areas adjacent to entrances within the greenhouse itself, thus creating an internal vestibule. There would be considerably less cost in this method. (See Figure 8.11).

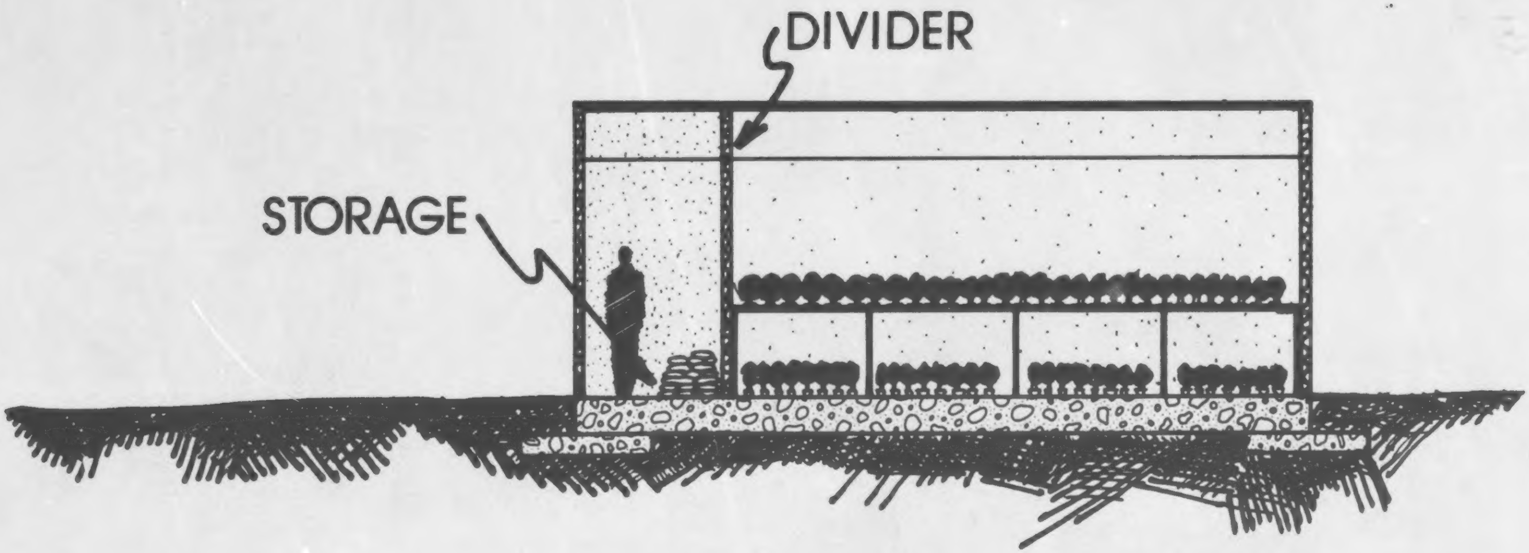

DIVIDER
STORAGE

fig. 8.11

vestibule

173

174

The average single-glazed greenhouse loses more heat in a winter day than it gains. Even a hothouse with a built-in passive solar system will lose in the long run if not properly insulated.

All glazed areas should be double glazed. Two layers of glazing provide an air space which helps to insulate. Thus solar gain is not significantly hampered while heat loss is reduced.

Separation of double-glazed walls can be built-in (structural) or can be activated by a blower fan which expands the glazing layers by forced air pressure.

All glazing should be sealed with caulking or weather stripping. This is especially needed if the structural supports are of a highly conductive material.(See Figures 8.12, 8.13, 8.14, & 8.15)

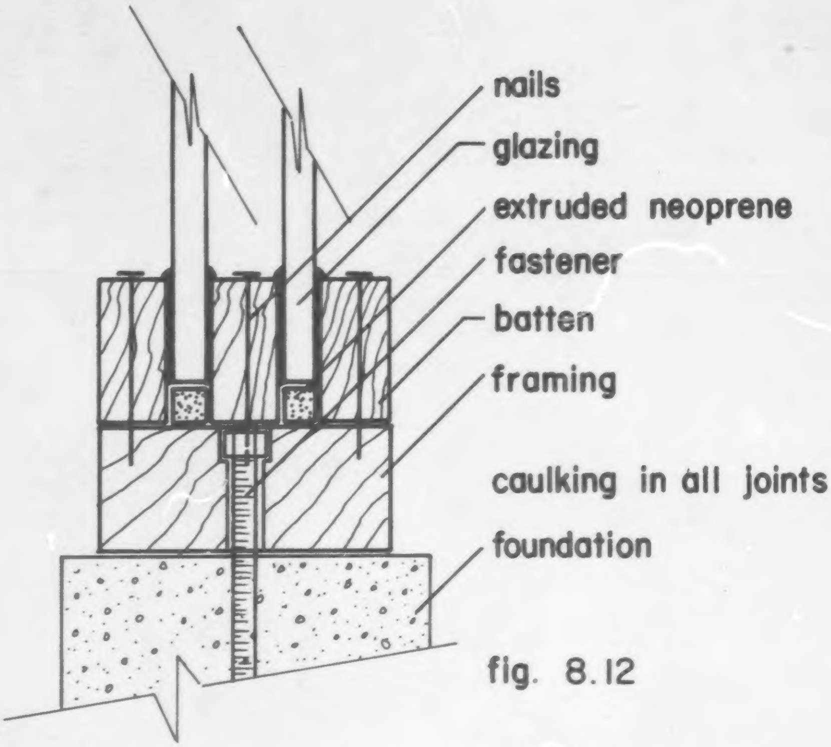

nails
glazing
extruded neoprene
fastener
batten
framing
caulking in all joints
foundation

fig. 8.12

foundation wall detail   side view / cross section

175

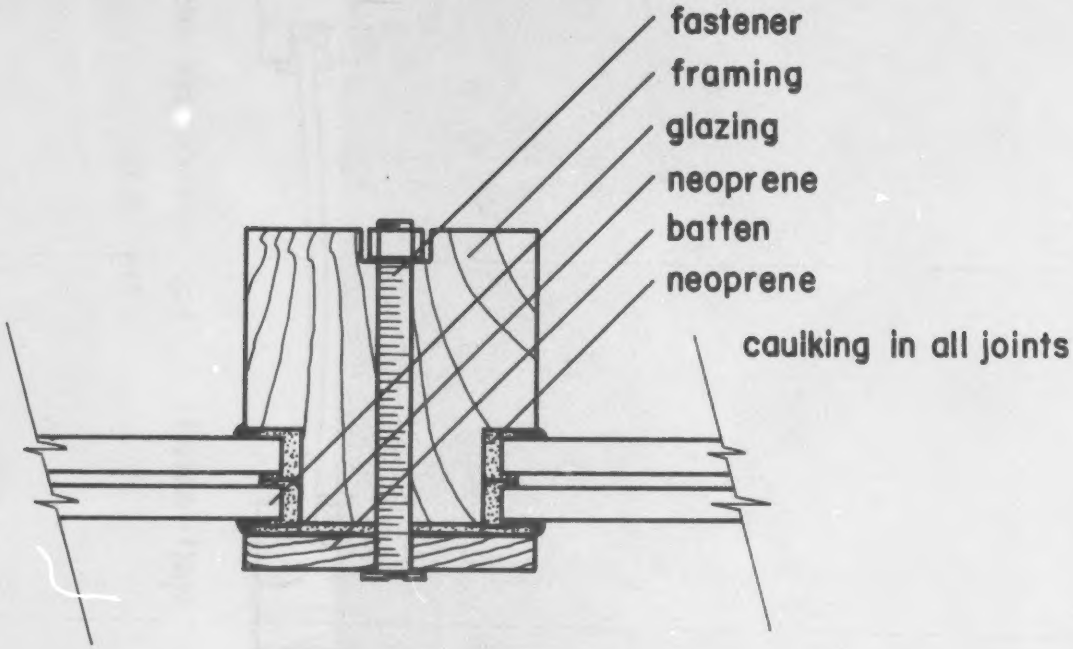
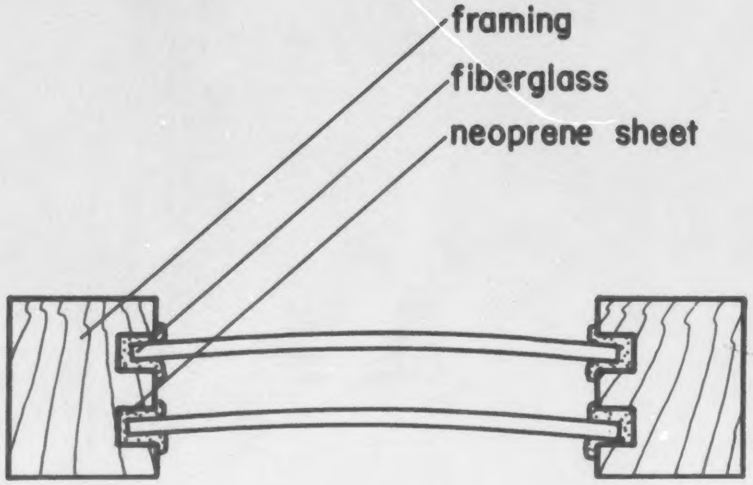

fastener
framing
glazing
neoprene
batten
neoprene
caulking in all joints

fig. 8.13 wall detail top view / cross section


framing
fiberglass
neoprene sheet

wall detail top view / cross section
fig. 8.14

177

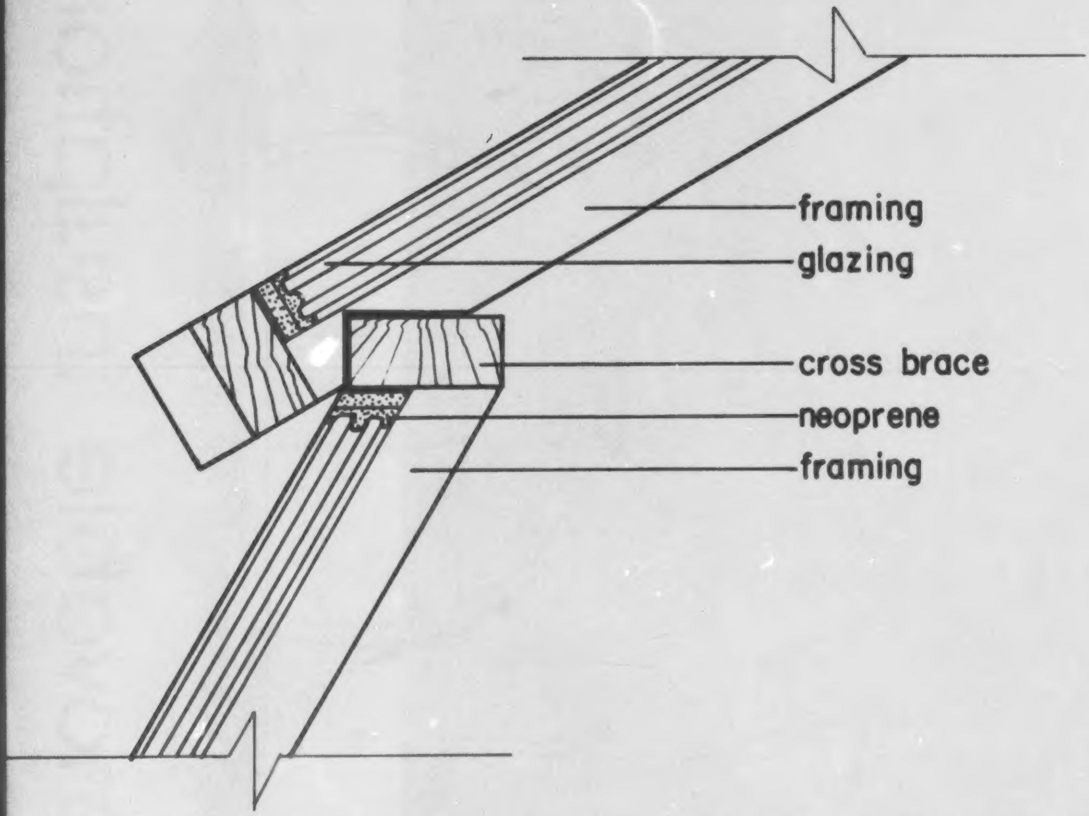

framing
glazing
cross brace
neoprene
framing

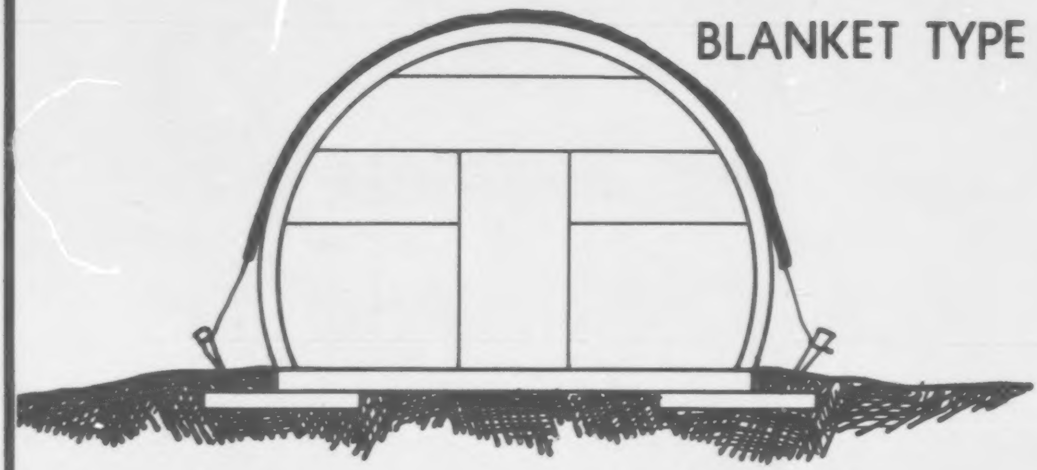
fig. 8.15 wall / roof joint side view / cross section

Another type of insulation which can be used with double glazing is movable insulation.

Types of insulation:

1. Fiber
2. Rigid foam
3. Particles

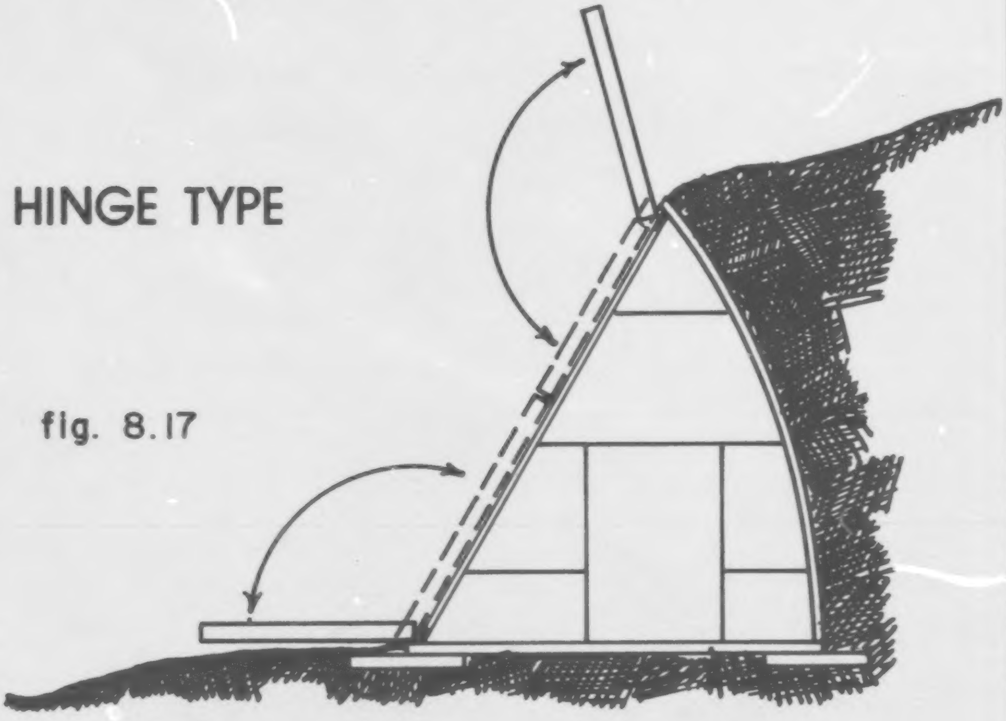
Structures with curved glazing surfaces will probably work best with a flexible fiber-type blanket. The blanket would be pulled aside during the 9 a.m. to 3 p.m. hours so that the unit is allowed to gain sunlight. In the afternoon, the blanket would be pulled over the unit and left until the next day.(See Figure 8.16).



movable insulation

fig. 8.16

Structures with flat glazing surfaces will work well with any type of movable insulation. The more rigid foam and particle types will probably last longer, however. These can be used as hinged panels which can be opened or closed as needed, similar to shutters. (See Figure 8.17)



HINGE TYPE

fig. 8.17

movable insulation

Insulation between the floor and ground of the structure (if masonry or other heat storage type) is not necessary unless the site is characteristic of wet soil. Since wet soil will steal more heat from the floor than will dry soil, waterproof insulation would pay for itself in a wet region.

Vertical masonry or water walls used for heat storage lose some heat to the ground through the floor. This amount is not large enought to justify the added cost of insulation, unless conditions are extremely harsh.

insulation for cooling

The greenhouse skin forms a partially isolated microclimate. Materials used to retain heat inside the structure are classified as insulation against heat loss. Materials used to keep heat outside are insulators against heat gain(i.e. insulation for cooling).

A material used to insulate against solar gain is loosely called a shade cloth or lattice.

Shade cloths are used predominately in the summer session to reduce the overall amount of heat absorbed by the greenhouse while still allowing ambient natural light to penetrate.

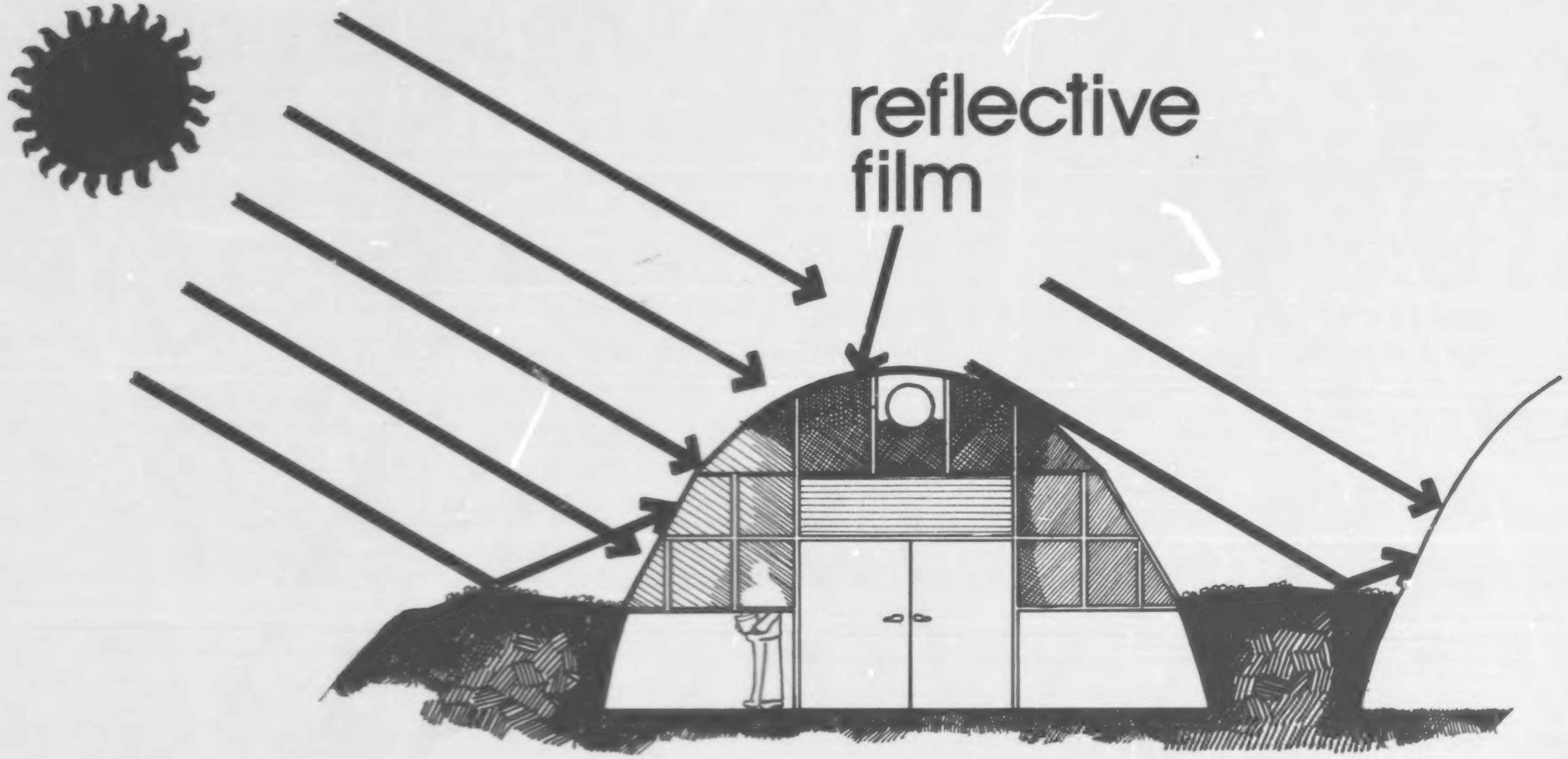
Possible alternatives for shade cover:

1. partially reflective films
2. perforated plastic blankets
3. paint-on type block-out (whitewash)
4. metalized foils
5. louvered shades

Shade covers to block sunlight can be combined with movable insulating panels or curtains to create one system capable of satisfying shading and insulating requirements throughout the seasons.

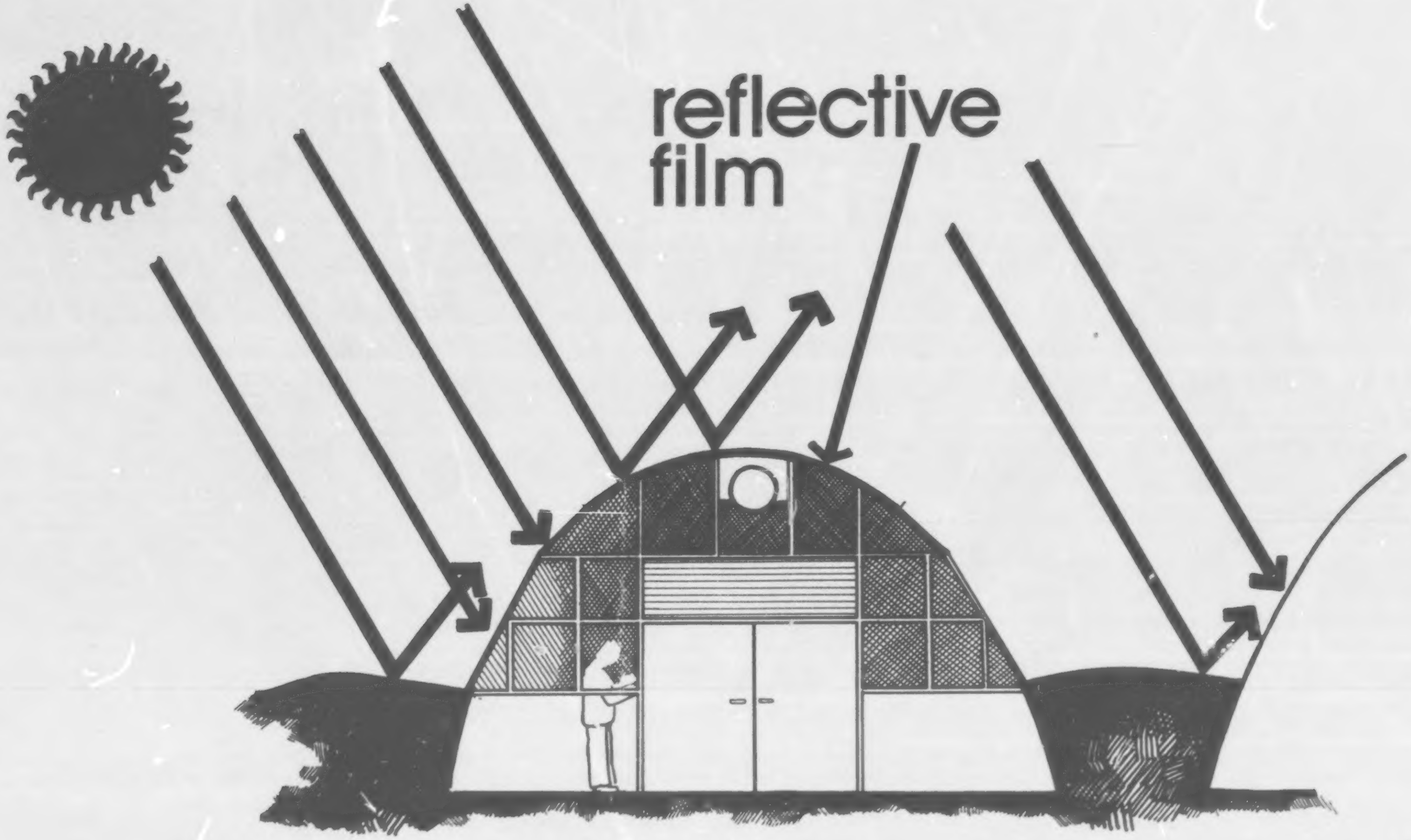
Since the summer sun imparts the majority of its energy to the roof of a structure, and the winter sun imparts the majority of its energy to the walls, a complementary system is conceivable which would reduce summer overheating without significantly impairing winter heat gain.

The concept involves the placement of reflective film or glass along the roof line. This added material functions as a kind of overhang, reflecting high-angle summer sun and allowing low-angle winter sun to penetrate. (See Figures 8.18, 8.19, & 8.20).


reflective
film

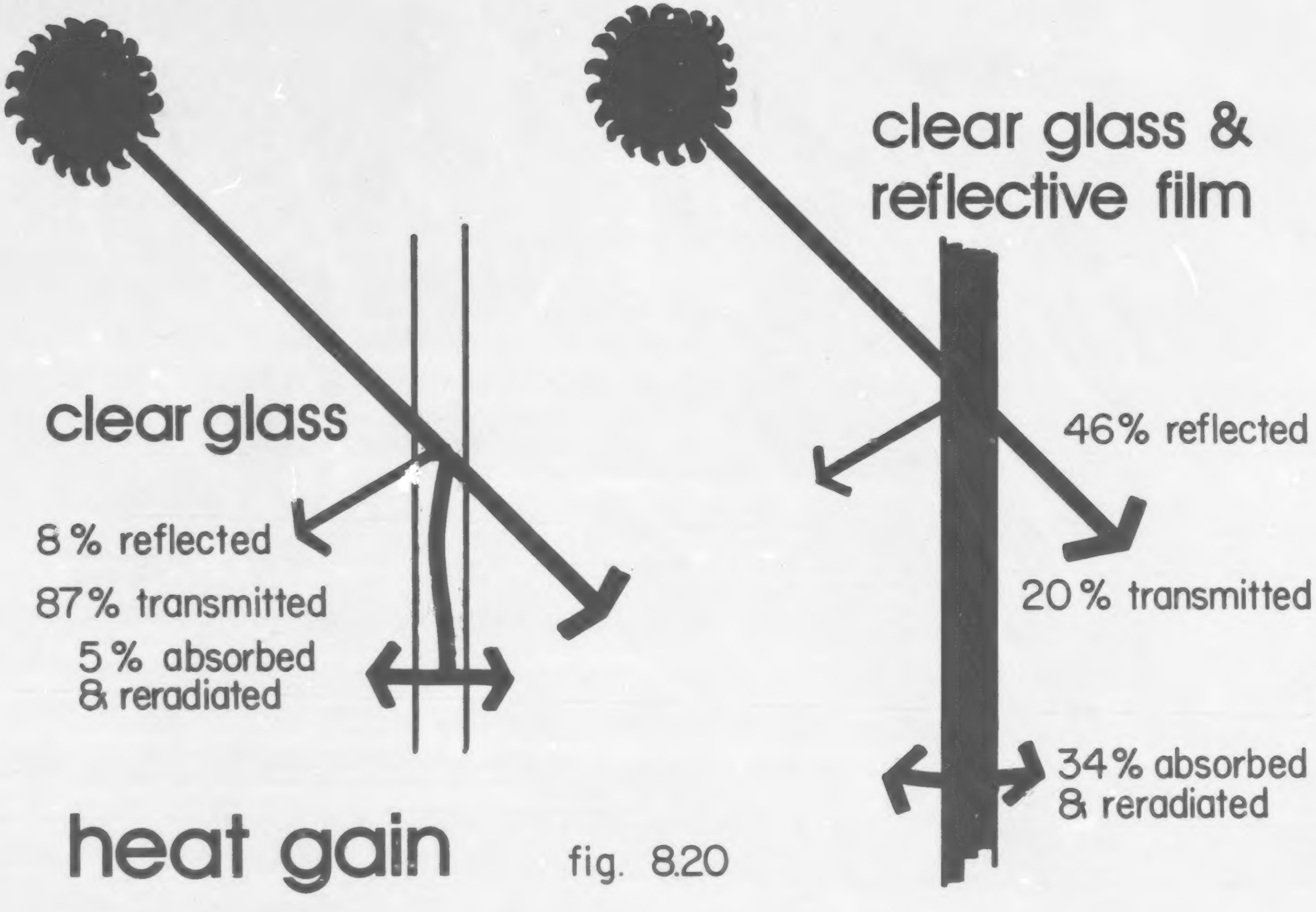
winter sun

fig. 8.18


reflective film

summer sun

fig. 8.19


clear glass &
reflective film
clear glass
8 % reflected
87% transmitted
5 % absorbed
& reradiated
46% reflected
20 % transmitted
34% absorbed
& reradiated

heat gain

fig. 8.20

ventilation

C. Most all greenhouses overheat to some degree during the warmer summer season. Overheating can be dealt with in several ways:

Ventilation is the oldest concept for removing heat from the structure by convection of wind currents. To accomplish ventilation the hothouse must be provided with windows, doors, etc., which can be opened to allow natural wind currents to exhaust the stored heat.

Since any part of the structure which opens (like a door) will be a source of heat loss in the winter, vent locations should be placed carefully and minimized.

The greatest amount of hot air will be found near the roof. A handful of vents placed on the roof line will extract hot air by making use of the thermodynamics principle (hot air rises, cool air falls).

To enhance this effect further, vegetation can be placed to channel summer breezes through the structure instead of around it.(See Figure 8.21).

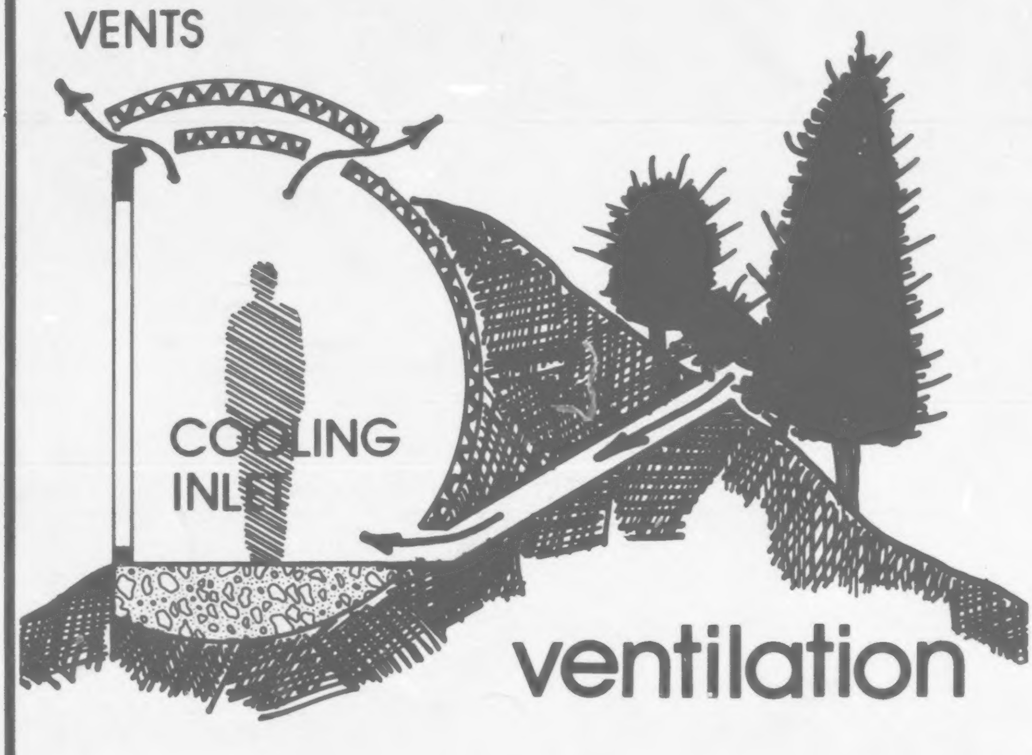


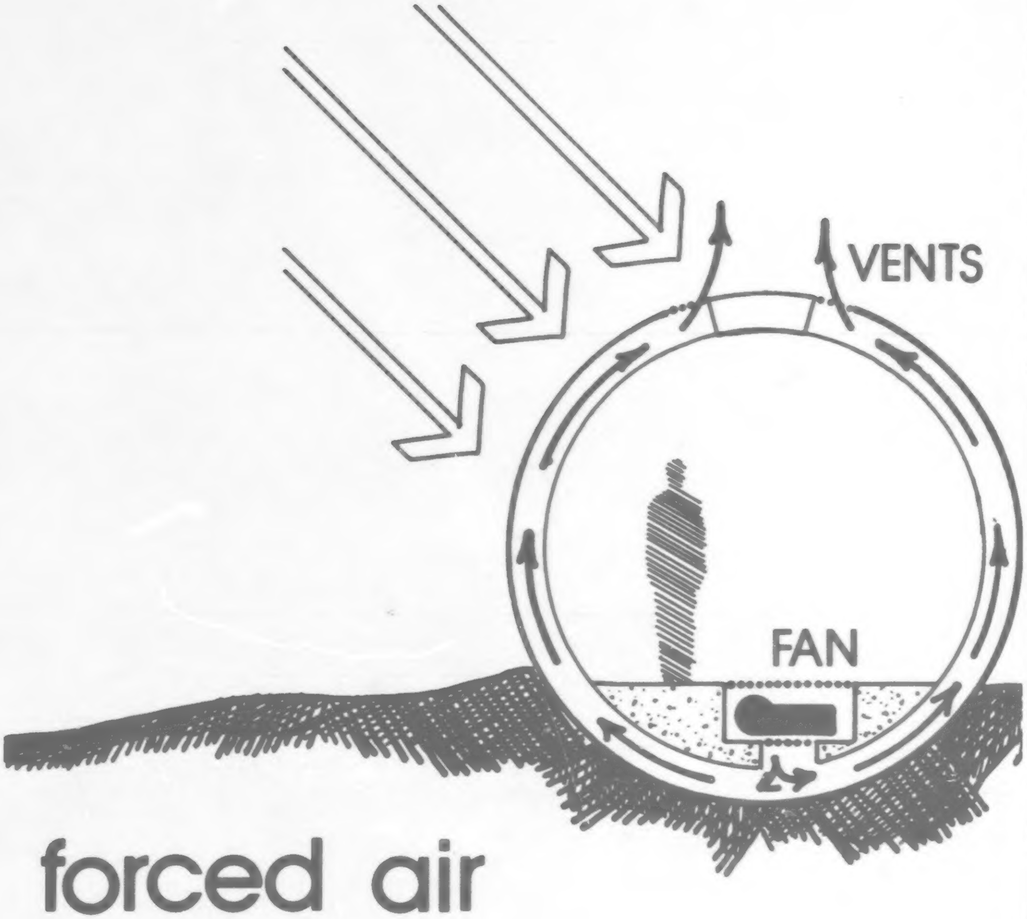
fig. 8.21

183

- Another principle useful to summer cooling involves the reversal of a concept used for winter insulation.

In a double-glazed structure, the first zone to gain heat through solar radiation is the space between the glazing. If this area is constantly vented, the system will remove heat from the first zone before it can reach the interior. The same "squirrel cage" fan which is used to create air space between glazing layers by inflation will function well as an exhaust fan.

True exhaust fans require energy input and should be avoided unless absolutely necessary.(See Figure 8.22)

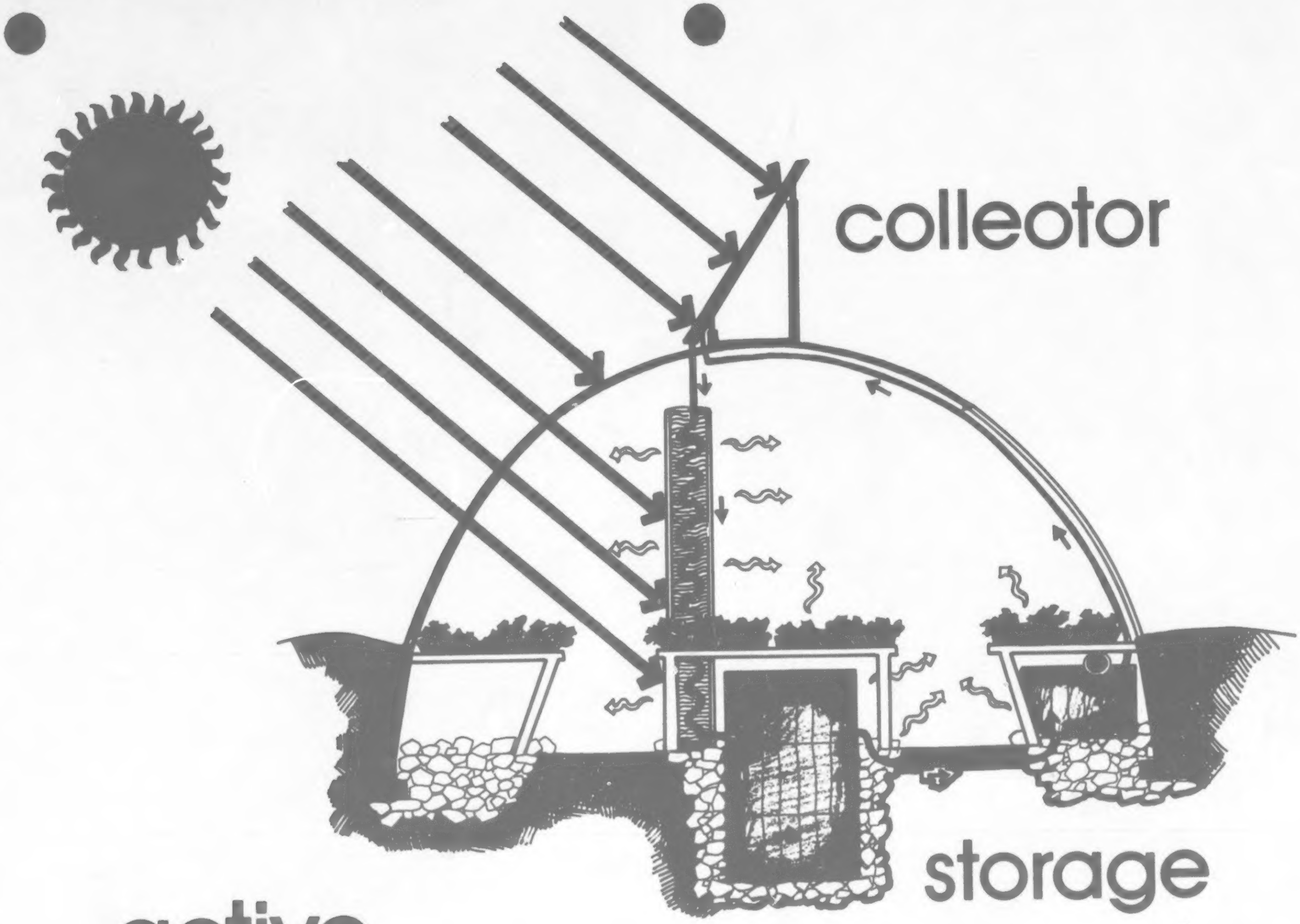


forced air cooling

fig. 8.22

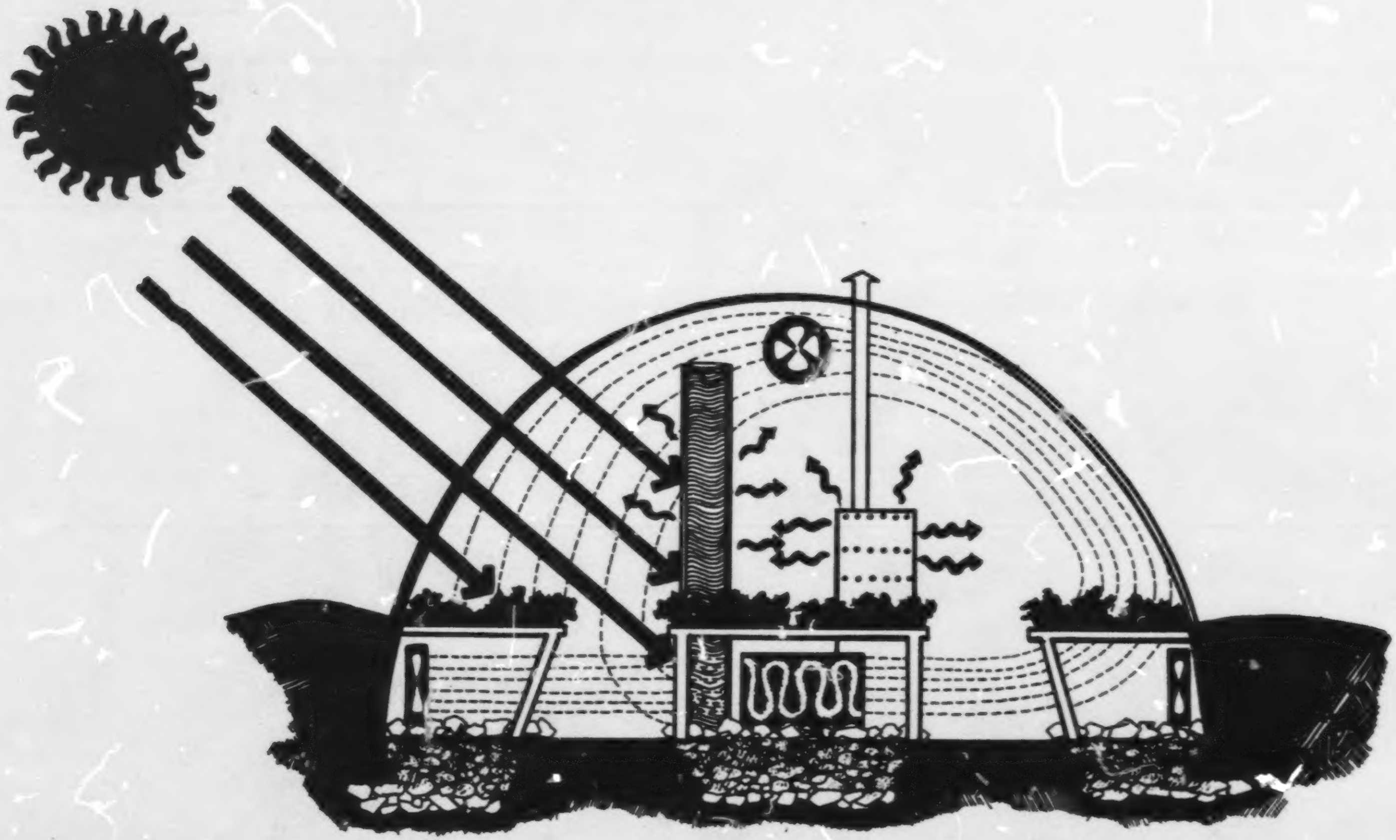
working systems

A successful greenhouse system will neutralize the extreme forces of nature. The degree of success will be determined by the energy required to maintain the system and make it work. To design systems to combat a force is genius. To turn one force against another is less tiring. Attention to the relationships of natural and man-made systems will allow you, the designer, to produce a more efficient, environmentally responsive structure. (See Figures 9.0 & 9.1).


colleotor
storage

active system

fig. 9.0



passive
system

fig. 9.1

Nursery Design and Operation for Energy Conservation

introduction

This book will deal with the design of a proposed nursery operation and with the techniques for conserving energy in the process. Each nurseryperson must be innovative in order to survive, so there will be many new ideas brought forth as we deal with our energy problems. This text lists the practical concepts at this time.

process

I. A nursery is a simple production unit to turn out first class plants efficiently with minimum effort. Changes have been a way of life in our technological society, and it is so today. During the past two decades we have seen enormous changes in the nursery business as a result of

1. New products--plastic film, plastic pots, peat pots, sophisticated watering systems, digging machines, pine bark, growing mediums, etc.;
2. An inexpensive energy cost based on the availability of natural gas, oil, and electricity, then rapidly escalating energy costs;
3. Expensive labor costs due to the rising costs of living correlated with minimum wage standards;
4. Increased constraints imposed by social legislation (OSHA, EPA, etc.); and
5. Improved chemicals for weed control, fertilization, and propagation.

We went from a labor intensive based production and landscaping program to a technological intensive based production and landscaping program based on the availability of inexpensive energy and products which were primarily oil based. We can say that we changed from human energy to oil energy. Now, since our inexpensive oil era is over, in order to survive we must change again, and fast, to new energy systems. This change will involve initiative, risk, ingenuity, and leadership. But that is what business is all about!

history

II. The nursery business in the thirties consisted of bedgrown cuttings, seedlings, and liners which were transplanted into rows or beds in the field. There they grew, were sold, were utilized in landscape plantings, were replanted further apart or were destroyed. The market was primarily local--within a few miles of the nursery. The nurseryman was a grower, retailer, designer, and landscaper. Many nurserymen ran tightly knit family operations which worked with known plants. Sometimes, specialty items like fruit trees, pyramidal arborvitaes, legustrum, etc., became the mainstay of the business. The nurserymen looked upon themselves as independent farming types, Many times their personal relationship to their product was one of deep affection, which they attempted to pass on to their customers.

Since that day, with the advent of newer concepts of propagation, fertility, weed control, container production, and mass consumer markets, the nurserymen have changed into sophisticated businessmen. They no longer look on individual plants with affection but on thousands of plants which must be nurtured, protected, grown, and sold to markets which were previously set up. There is now no room for a hit-or-miss approach.

the nursery

III. There are many types of nurseries from the extremely large ones that cover hundreds of acres and produce thousands of plants each year down to the one- or two-acre nurseries which may produce only one type of plant, for example, Japanese Maples, in great variety. The monies from one type might be as great as from the other. So larger does not necessarily mean better or even more productive and cost effective.

Therefore, the first question to ask ourselves is how big do I want to be? If you like the individual approach, then do it; but, if you invision yourself more in a management role, a leader of workers, then the larger operation is probably where you will go. In both cases, a wise utilization of your natural and human resources is necessary for success.

natural resources

IV. What are our natural resources and how can we efficiently use these resources?

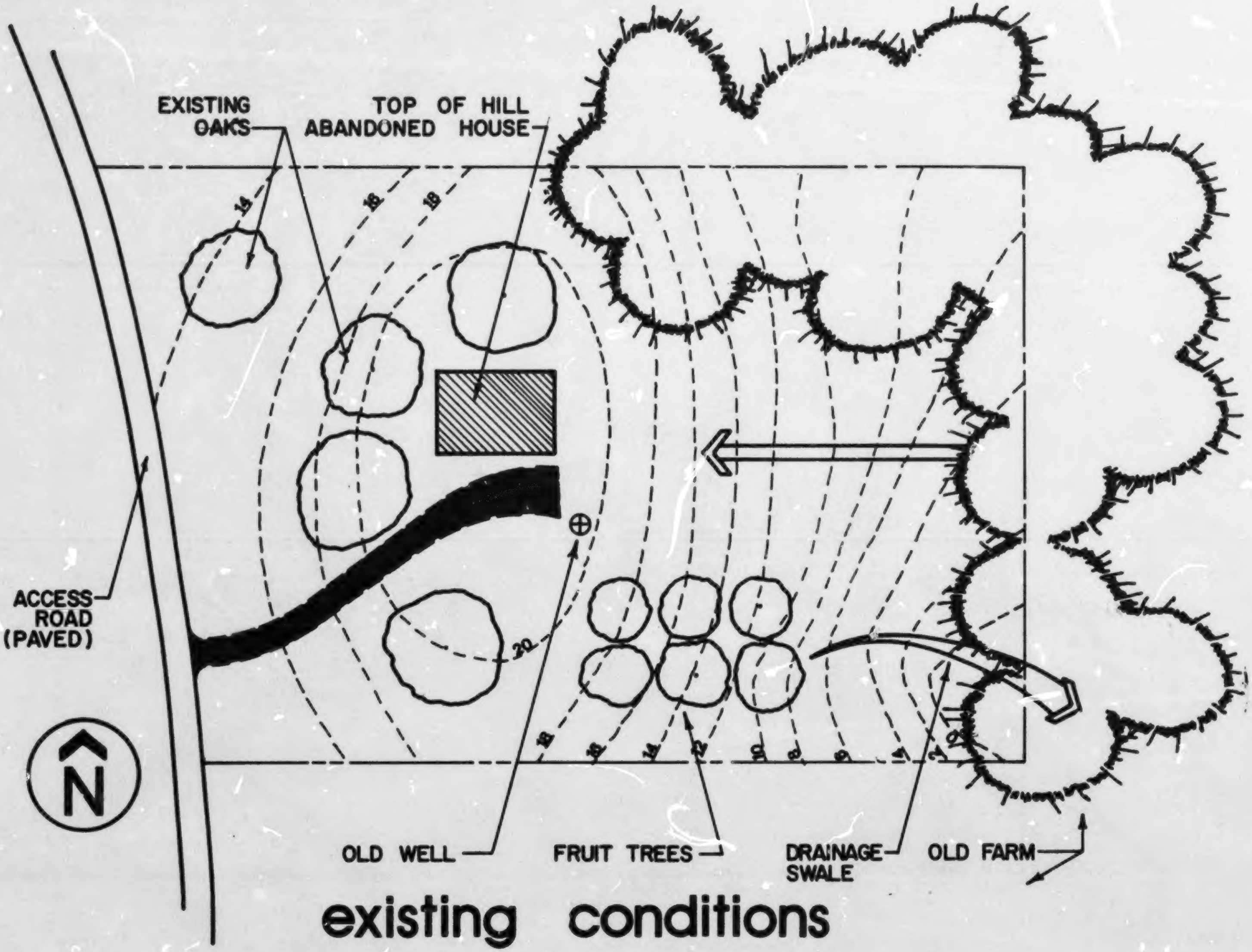
First, we have the land. What are its natural characteristics--wooded, cut over, or cleared. What are its landforms--rolling, flat, steeply sloped, deeply incised with gulleys. How does the dirt feel--porous, tight, filled with humus, moist, dry? How wide is it? How long? What is its orientation? Where is north or south?

Second, we have the vegetation and soils. Do the trees cast shadows? Are the trees evergreen or deciduous? What is the chemistry of the soil? Can we easily clear the land--by manual labor or by bulldozer? What do we destroy if we use the bulldozer? What is the soil naturally growing? Does the existing vegetation have a market value? Can the humus be used as a growing medium? Are there any old sawdust piles? Can the trees be cut up into building lumber?

Third, do we have an available water supply--an old well, an abandoned pond, a running brook?

We should record the existing natural conditions and resources and from this information begin a plan. A good topographic map is a necessity, so do not hesitate having one prepared by a surveyor. The plan can be drawn on any kind of paper and at any scale. The topography and the size of the land unit determine the contour intervals and the scale. It is best to draw the total project on one sheet of paper and the paper size should not exceed 30 inches width by 42 inches length. Drawings on cardboard can be photostatically put on tracing paper. The scale probably will be one inch equals 20 feet (1"=20', or perhaps 1"=30' or 1"=40' or 1"=50') with contour intervals of two feet. The illustration (figure 4.1) shows the proper order of placing information on your paper.

fig. 4.1


EXISTING OAKS
TOP OF HILL ABANDONED HOUSE
14
16
18
20
ACCESS ROAD (PAVED)
N
OLD WELL
FRUIT TREES
DRAINAGE SWALE
OLD FARM
18
16
14
12
10
8
6
4
2
0

existing conditions

By a study of the existing conditions plan, we can determine the following

1. Access
   Where should the major driveways be placed for initial operations, then permanent operations?

2. Vegetation and Other Natural Features
   What trees should remain? What can they be used for? The combination of landforms (i.e., contours), orientation (i.e., solar and winds), and existing vegetation determine the net usable spaces on the land. For example, a row of densely planted evergreen trees and shrubs on the north creates a protected area on the south. Tall trees, particularly pines, become effective natural lathhouses with light shade.

3. Structures

   Can the old house be used as a temporary dwelling, rehabilitated into a permanent dwelling, used as an auxillary building, moved to a new location, material salvaged and reused, or material used as firewood or temporary erosion control structures?

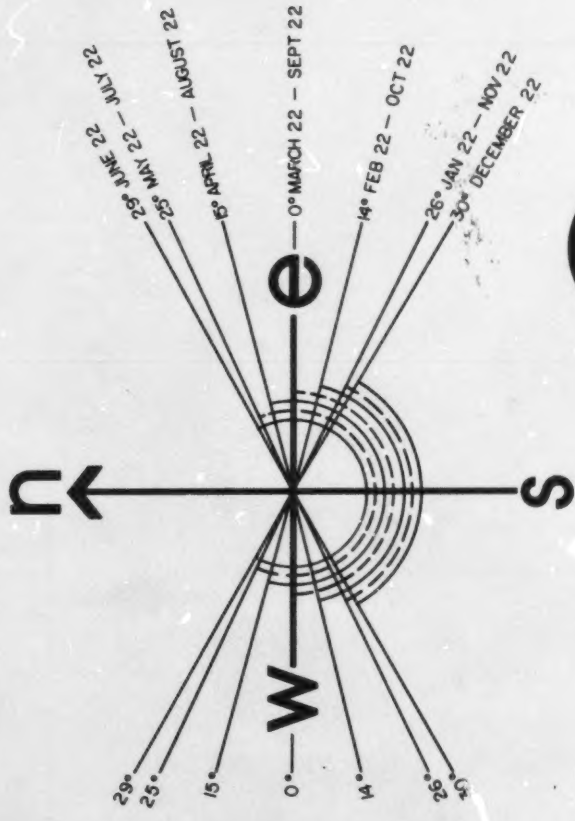
4. Landforms

   Slopes and drainage--find the areas which are well drained and less than one percent gradient (i.e., a one foot vertical change in a 10 foot horizontal change); these areas are the easiest ones to develop.

5. Orientation

   There are several bits of knowledge that should be considered at this stage:

   a. Solar. The sun goes from southeast to southwest in the winter and northeast to northwest in the summer. (See Figures 4.2 and 4.3)

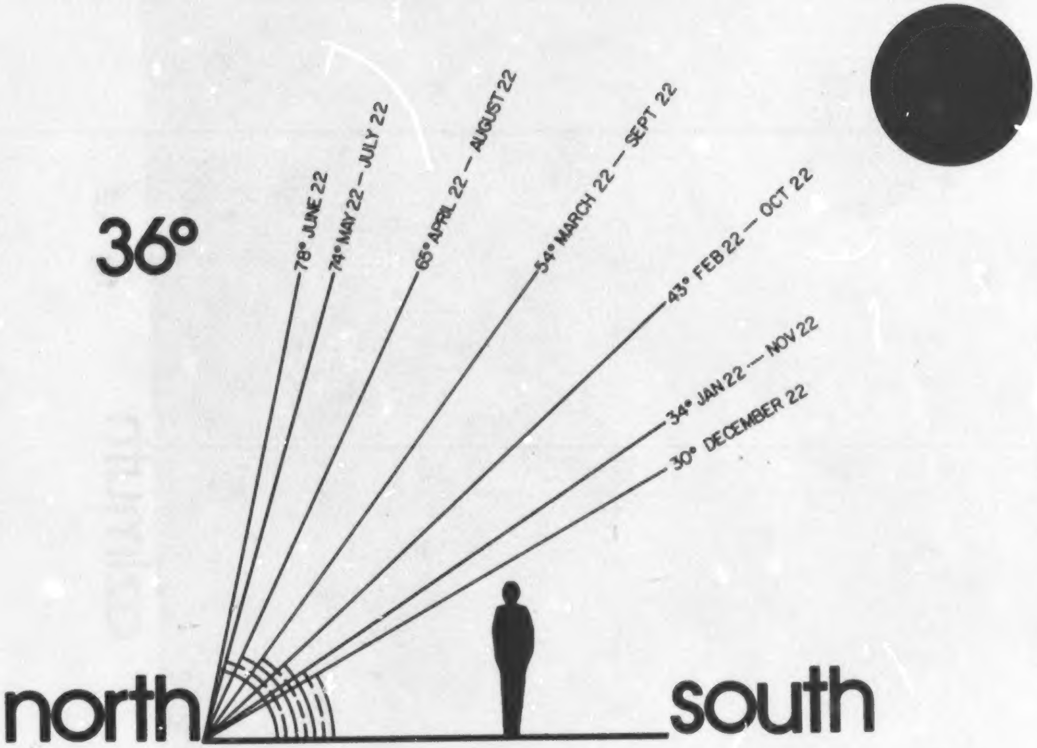

29° JUNE 22 — JULY 22
25° MAY 22 —
15° APRIL 22 — AUGUST 22
0° MARCH 22 — SEPT 22
14° FEB 22 — OCT 22
26° JAN 22 — NOV 22
30° DECEMBER 22
e
n
s
w
29°
25°
15°
0°
14°
26°
30

36°

azimuth fig. 4.2

fig. 4.3

altitude


36°
78° JUNE 22
74° MAY 22 — JULY 22
65° APRIL 22 — AUGUST 22
54° MARCH 22 — SEPT 22
43° FEB 22 — OCT 22
34° JAN 22 — NOV 22
30° DECEMBER 22
north
south

b. Winds. Winds combined with extremes in humidity and temperature can severely damage unsheltered plant materials. Warm dry summer winds (generally from the south to southeast) can force plants to transpire excessive amounts of water in order to maintain an equilibrium. The plant will eventually dehydrate and die.

The cold winds are from the north. Cold wet winter winds bring frost and are also destructive to plants. Extreme shifts in climate can be detrimental, especially when warm days are followed by a cold snap.

Existing windbreaks of tightly grown evergreens on the north side of the property can protect plants, people, and structures from the cold winds.

Windbreaks on the south and southeast quadrant can be used to restrict summer winds which cause dehydration. These plantings should be placed so as not to restrict solar gain to structures in the winter months.

Swirling winds or small tornadoes can be very destructive to unsecured or cheaply built structures. Windbreaks which either filter or divert strong air currents will reduce damage caused by the sheer force of the wind.

c. Air Layering. Cold air normally migrates to the lowest part of the land and, in some instances, will layer for several hours or days which could be terribly destructive to very sensitive plant materials. Therefore, locating field stock in a depression or valley to shelter it from cold northern winds would only create a new problem. Natural earthforms will work well as wind barriers provided they are not extreme depressions into which cold air will settle and become stagnant.

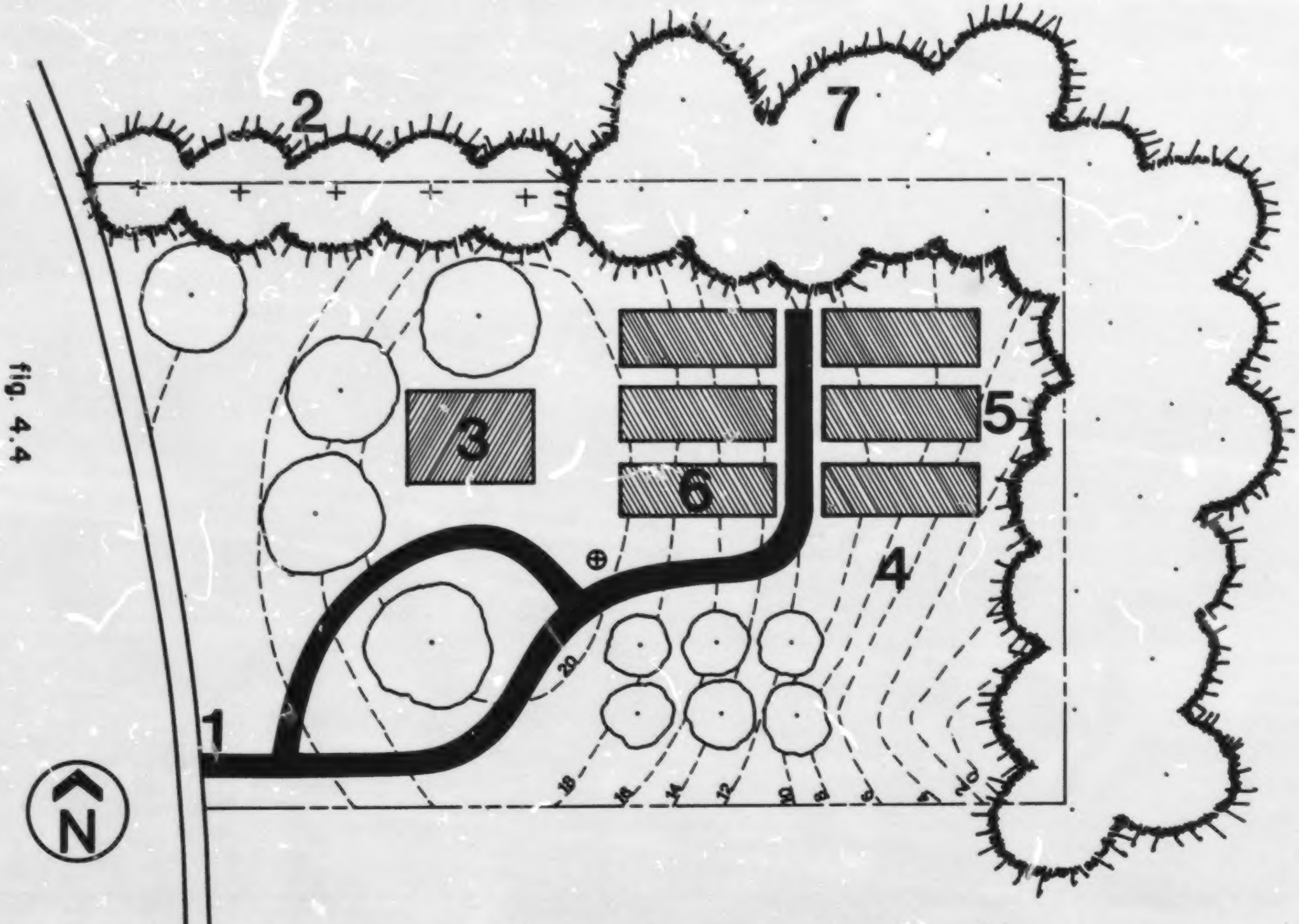
6. Temporary Assets

The landforms and existing vegetation which are on adjacent lands to your property can be looked at as temporary assets. To base the layout of your property on the existing situations beside you would be hazardous since the adjoining property could be changed through grading or vegetative cutting at any time.

What have we learned to this point that we can incorporate into our plan?

1. Access. Good vision of approaching or passing vehicles. access to house and business.
2. Vegetation. Pine stand on north to remain; augment with evergreen screen to shelter against north winds. Pine stands on adjacent properties are good additional buffer areas.
3. Structure. Repair the old house; add to later on; or replace at some future date.
4. Landforms. Good slope and well-drained soils.
5. Orientation. Shade, sun, cold winds, cold pockets.
6. Ideal developable unit.
7. Temporary assets. Adjacent properties.

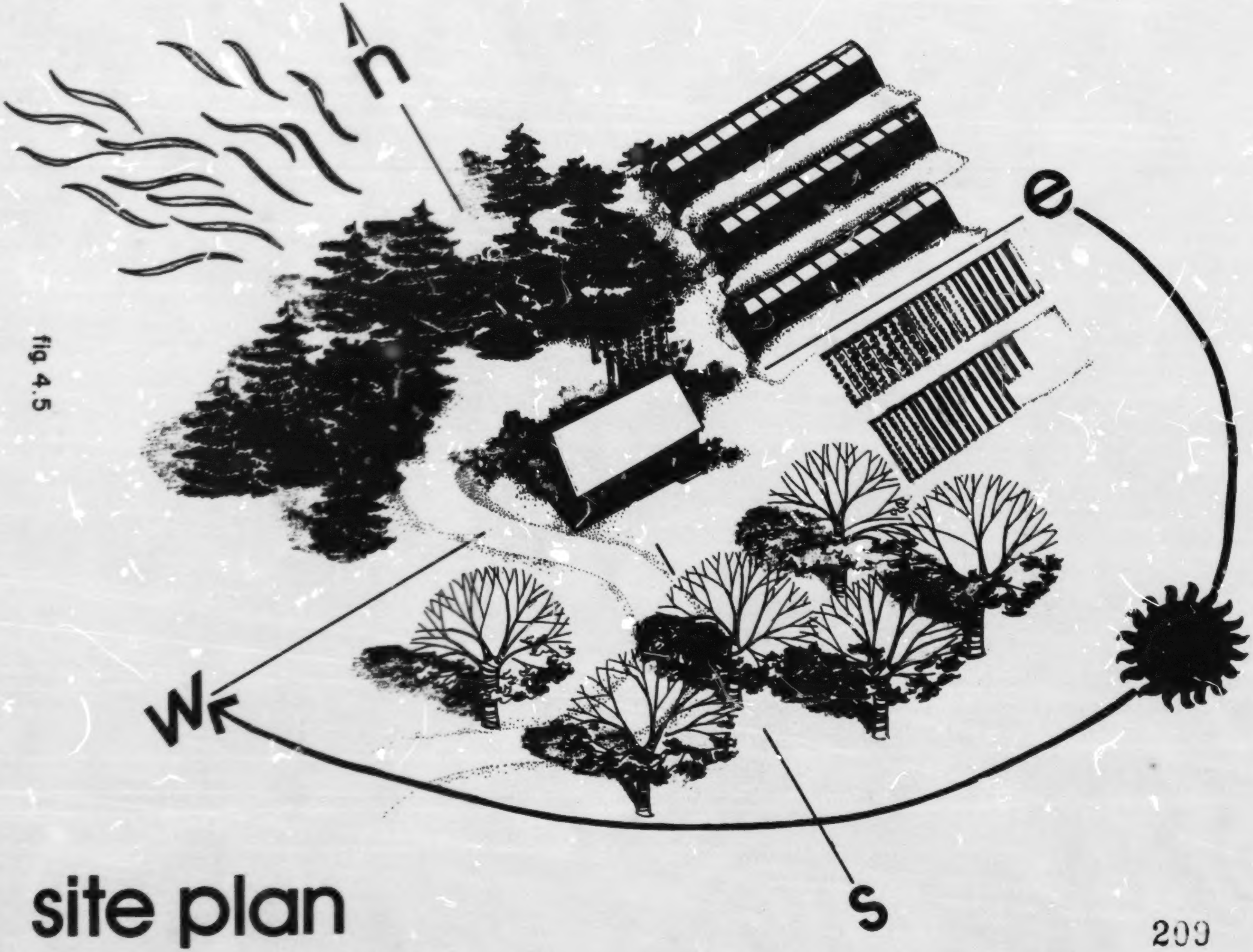
fig. 4.4


2
7
3
6
5
4
1
N
20
18
16
14
12
10
8
6
4
2

proposed nursery layout

The layout of our small nursery begins to take on the following appearance (See Figure 4.5)

fig. 4.5



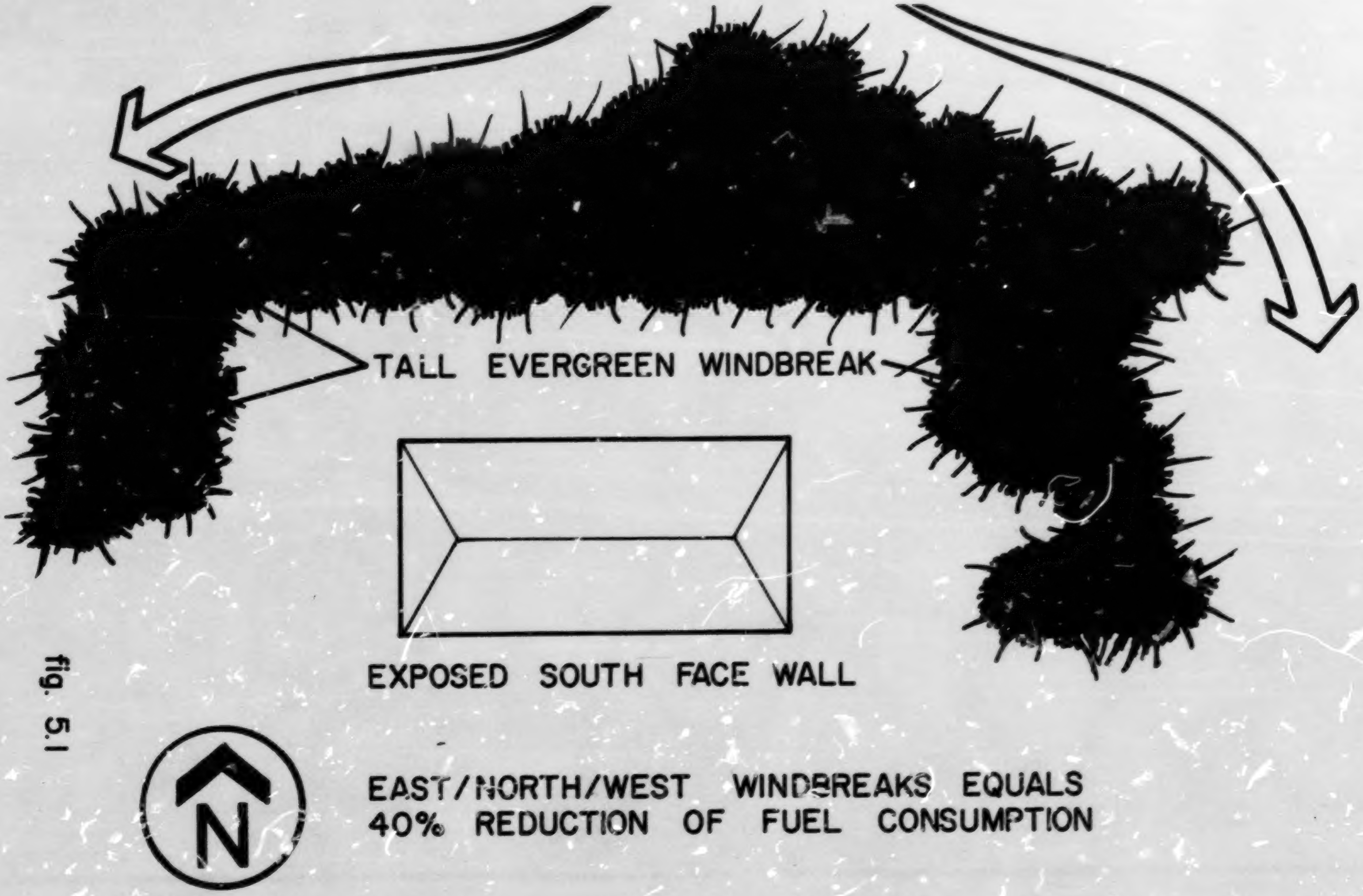
site plan

energy conservation

V. The concept of energy conservation should pervade every aspect of your nursery design, construction, and operations.

   A. Design as previously shown takes into account existing topography, existing vegetation, solar orientation, maximum utilization of natural resources, location of facilities, access and parking requirements, prevailing winds (both winter cold and summer cooling), water capacity, and land clearing. We can state the following energy (i.e., money) saving principles.

      1. The existing vegetation can be an important factor in energy conservation. The following figure illustrates data from the Twin Rivers, New Jersey, study by the U. S. Department of Commerce (see figure 5.1).


TALL EVERGREEN WINDBREAK
EXPOSED SOUTH FACE WALL
N

EAST/NORTH/WEST WINDBREAKS EQUALS
40% REDUCTION OF FUEL CONSUMPTION

fig. 5.1

2. The existing vegetation can be supplemented by large, medium, and small evergreen shrubs to effect a channeling of wind yet add beauty to your landscape (see figure 5.2).

10 MPH WIND FROM NORTHWEST

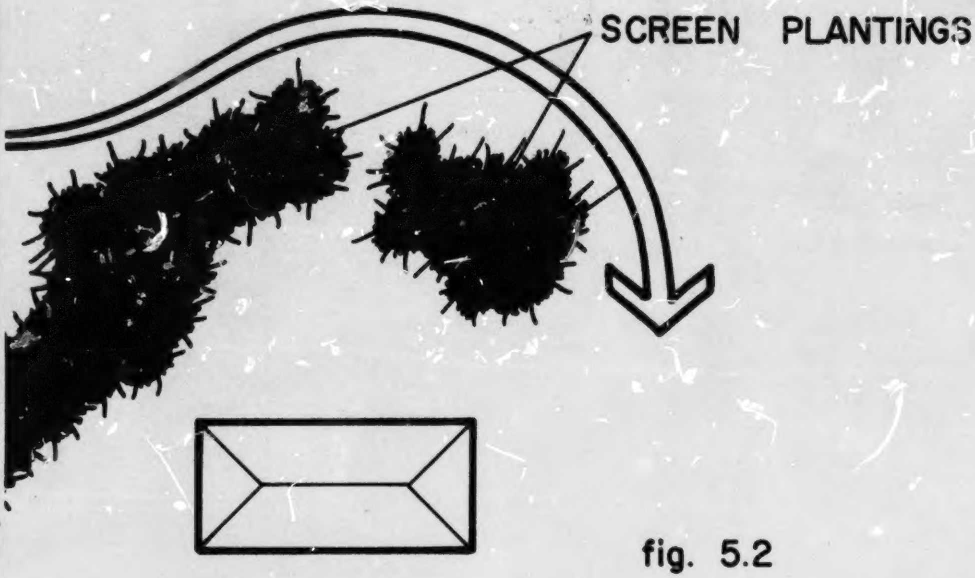


fig. 5.2

PLANTINGS AS FUNCTIONAL/AESTHETIC ELEMENTS

3. In the design of the house, sheds, and general structures which are considered weatherproof, you should enclose and insulate the sides facing northwest to northeast. Open up the sides facing from the southeast to southwest with window glass to allow solar(heat) to penetrate in the winter months (see figure 5.3).

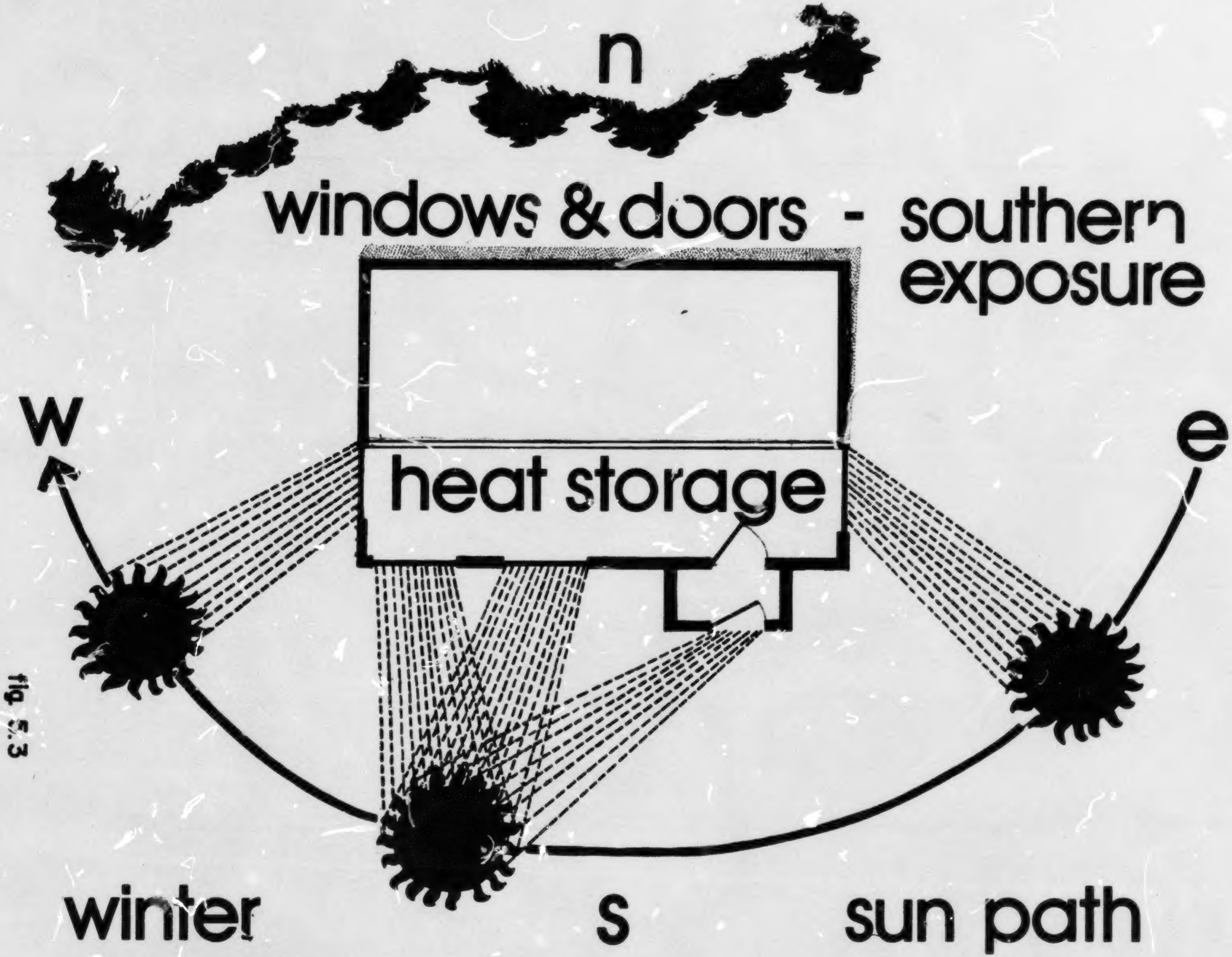

n
windows & doors - southern exposure
heat storage
w
e
winter
s
sun path

fig. 5.3

4. Keep or plant deciduous trees on the south faces of the structures so that the trees will shade in the summer months, yet allow solar heat in during the winter months (see Figures 5.4a and 5.4b)

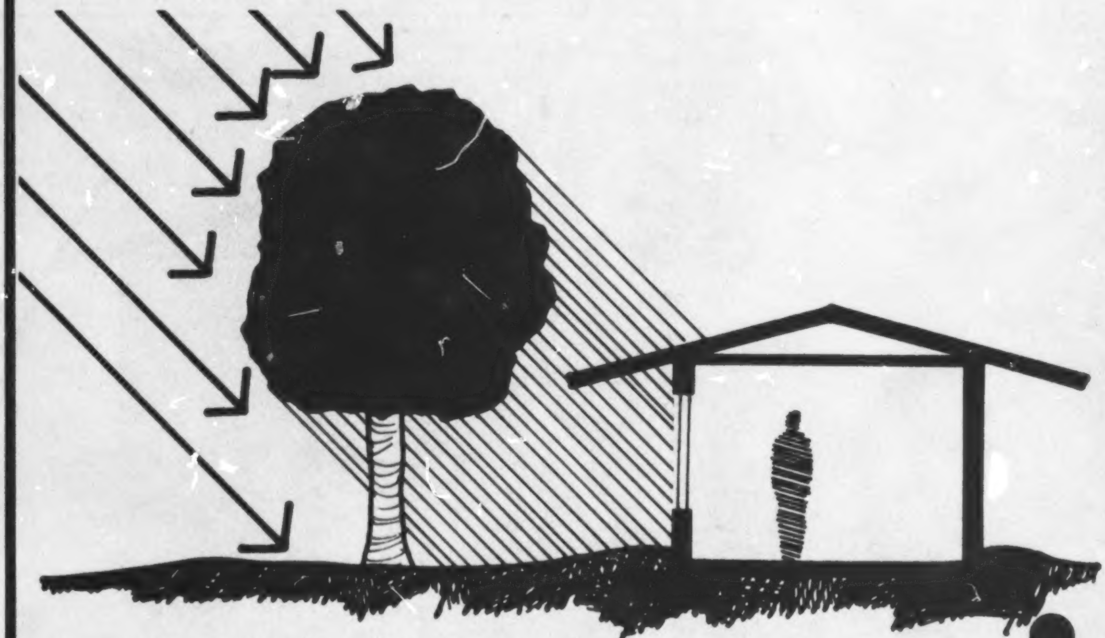


fig. 5.4a deciduous tree - summer

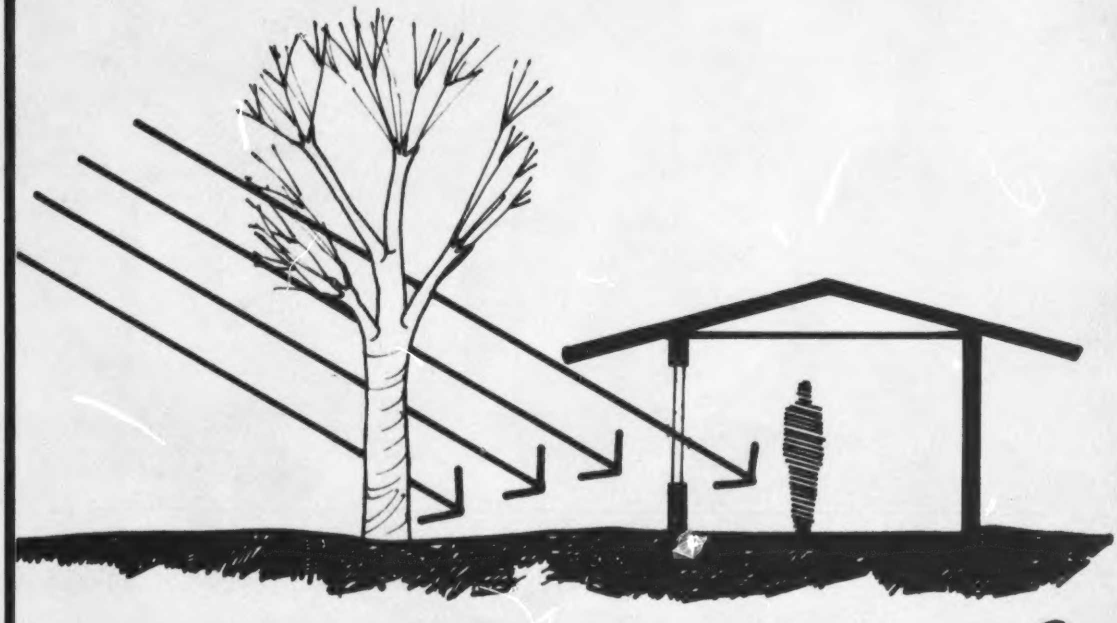
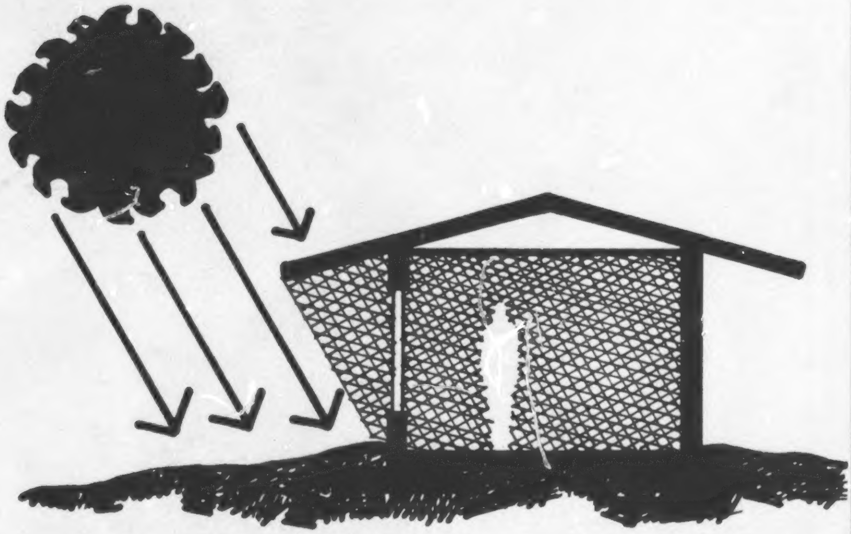
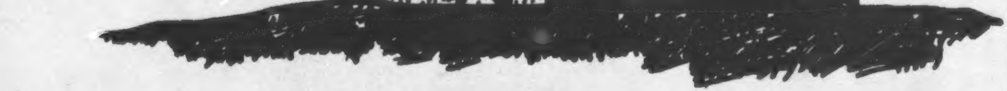


fig. 5.4b deciduous tree - winter

5. Use the principle of overhang and vestibule in the design of your structure (see figures 5.5 and 5.6).



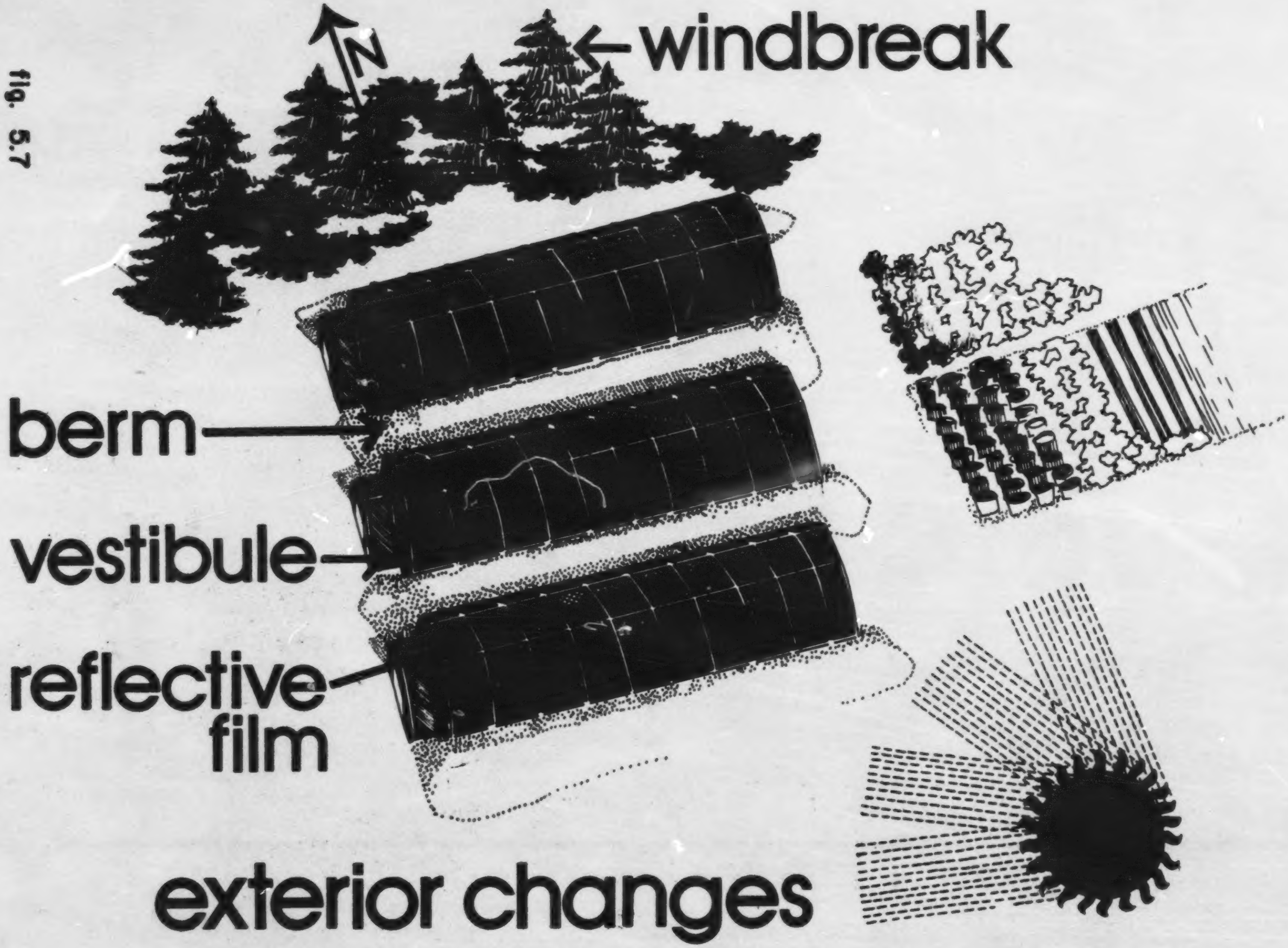
overhang fig. 5.5



vestibule fig. 5.6

6. Utilize the same principles in the design of your greenhouses. Also, consider a more permanent greenhouse with the use of a double layer of plastic or a reflective plastic for insulation which provides a greater insulation value--up to sixty percent saving in heating (see figure 5.7).

fig. 5.7


N
windbreak
berm
vestibule
reflective film

exterior changes

7. Drainage of plant beds is important and should be considered at all times. However, the energy (costs) of a bulldozer will be ever increasing so the amount of grading should be kept to a minimum (see figure 5.8). In addition unecessary grading can create the following problems.

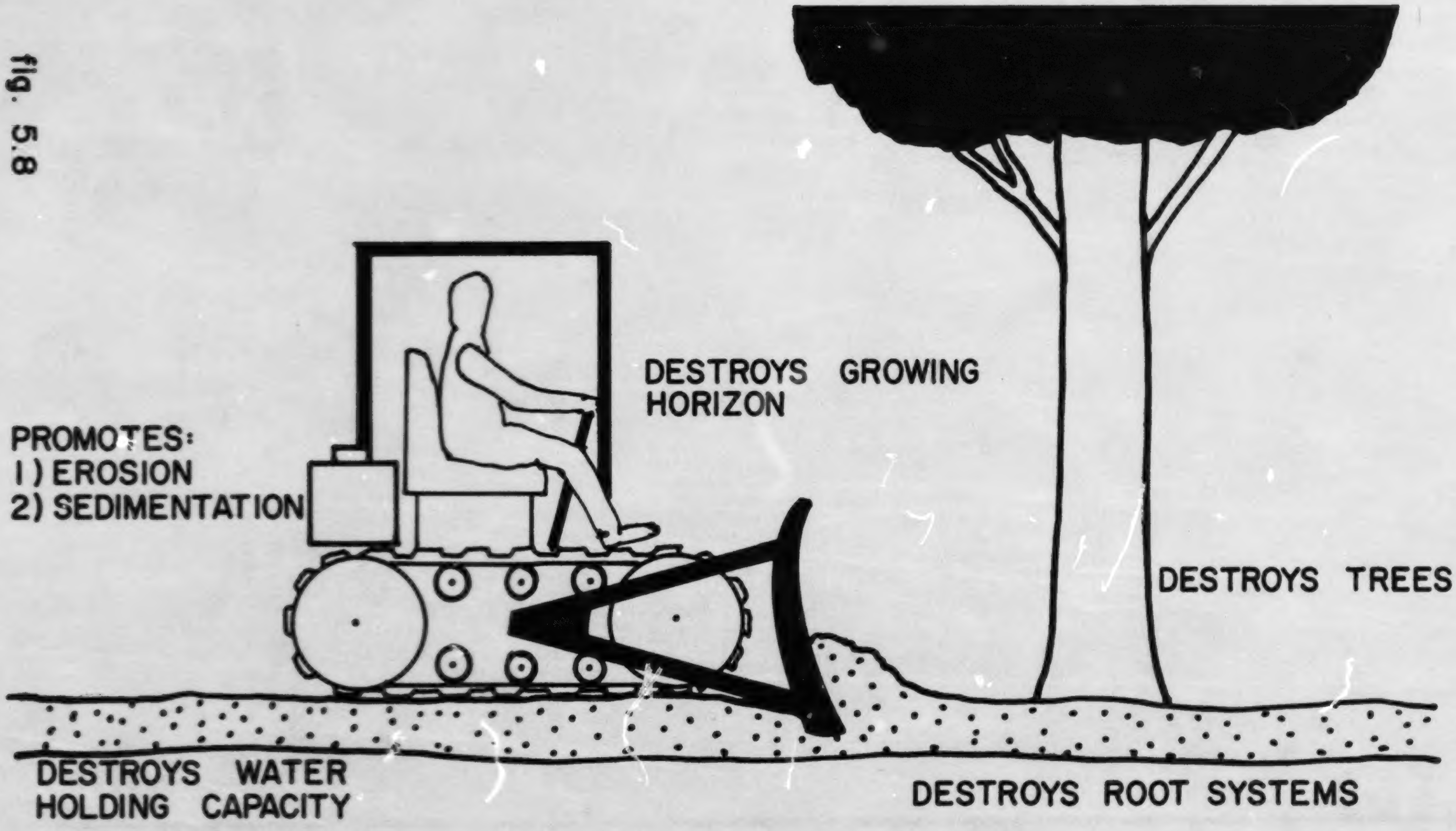
   a. Destroys the growing horizon for most trees and plants; expensive to replace.

   b. Destroys root systems of trees.

   c. Destroys the water holding capacity of the soils. Creates destructive run-off and sediment pollution.

   d. Destruction of trees which could be beneficial for summer shade or winter screening. Expensive to replace, plus growing time involved.

fig. 5.8


DESTROYS GROWING HORIZON
PROMOTES:
1) EROSION
2) SEDIMENTATION
DESTROYS TREES
DESTROYS WATER HOLDING CAPACITY
DESTROYS ROOT SYSTEMS

B. The construction of buildings has been previsously discussed; however- it should be emphasized again that a low building front-end cost may lead to expensive maintenance and operation costs through the years to come. Proper planning would be to design the building so that it could be increasingly improved through the years by addition of insulation, filling in open cracks, tightening up of window and door spaces, and additions of vestibules. Remember, heat goes to cold, so every open cavity or crack is an escape hatch for heat (energy).

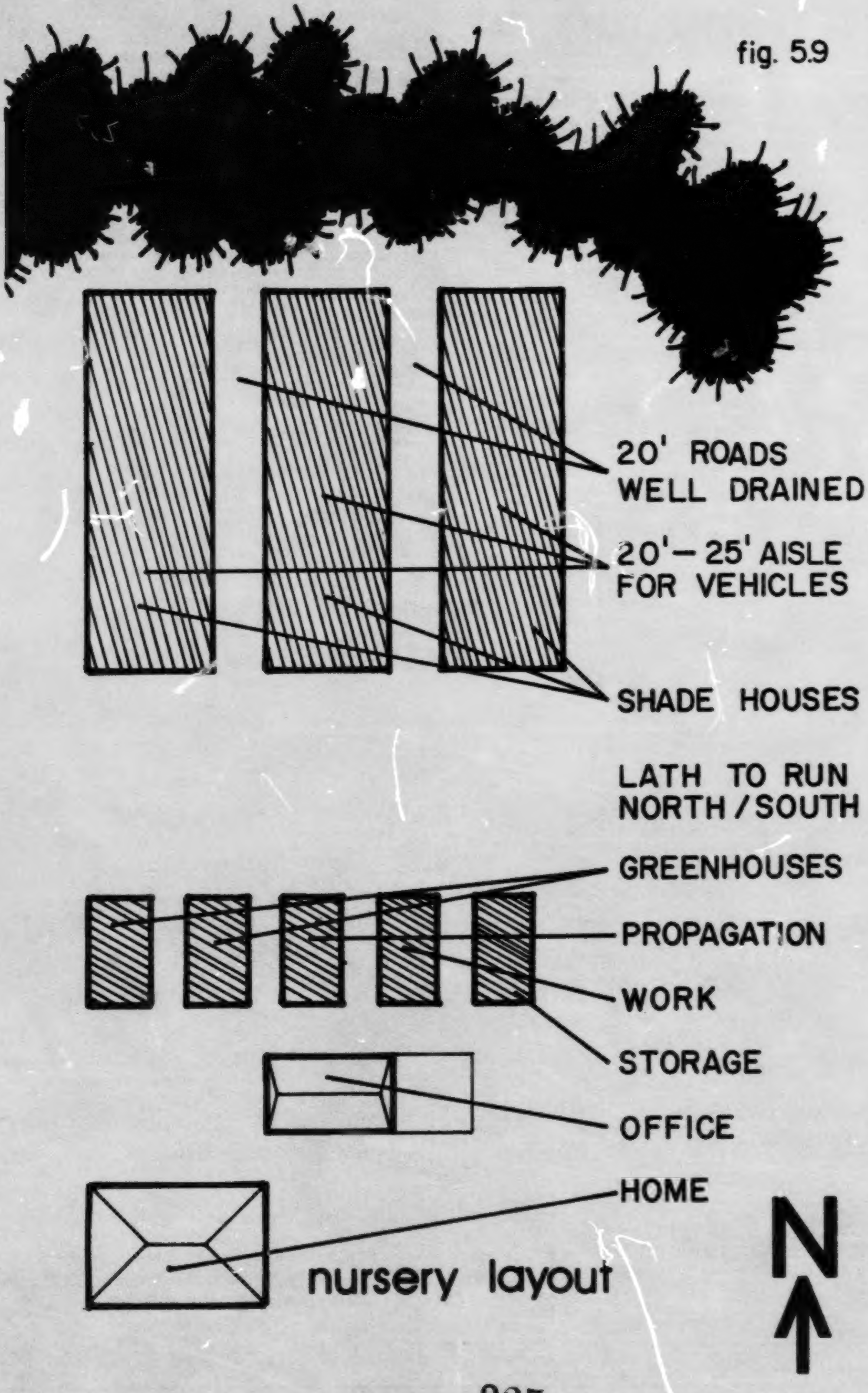
C. Operations of a nursery must be based on efficient design and management. Your profit potential can be maximized only by minimizing waste in the growing process.

The costs of operating labor-saving devices must be evaluated constantly against the costs of labor.

1. The costs of labor must be evaluated constantly in terms of maximization of
   a. work patterns,
   b. relationships of workers to equipment,
   c. equipment repairs, and
   d. nursery's potential.
2. The cost of labor-saving devices (i.e., mechanical equipment) must be evaluated in terms of
   a. operating costs,
   b. maintenance costs,
   c. relative productive time, and
   d. storage (weather protection) costs.

Transportation of materials, equipment, and personnel will become more expensive; therefore, a good layout is important. The following plan shows in a diagrammatic way the relationship of elements (see figure 5.9).

fig. 5.9


20' ROADS
WELL DRAINED
20'—25' AISLE
FOR VEHICLES
SHADE HOUSES
LATH TO RUN
NORTH / SOUTH
GREENHOUSES
PROPAGATION
WORK
STORAGE
OFFICE
HOME
N

nursery layout

225

summation

As the facts and figures begin to come in on your operation, you will need to analyze them and make the necessary changes to maximize your profits. The preparation of an energy conservation plan will be a must since, before you can properly manage and conserve your resources, you must plan how to do so. The energy conservation plan should take into account:

1. an analysis of current costs,
2. how to reduce energy wastes,
3. how to recycle wastes, and
4. a procedural plan for efficient energy use.

Your energy conservation plan will not only be valuable to you, but will be valuable to the nursery industry. New techniques for energy conservation will come forth from now on, and your solution to the problem could be the next important step!

The following chart and methodology may be useful in evaluating the efficiency of your operation.

The performance chart is used to determine the degree of efficiency within various systems and other related systems.

To use the performance chart:

1) determine if a relationship exists between two areas.
2) describe the extent to which a particular system affects or interacts with another.
3) define measures which would inprove efficiency and decrease waste within the relationship.

PERFORMANCE CHART	STRUCTURES	LANDSCAPE	LABOR	MAINTENANCE	TRANSPORTATION	LAYOUT
STRUCTURES						
LANDSCAPE						
LABOR						
MATERIALS						
TRANSPORTATION						
LAYOUT						

* note: other input may need to be added; depending on the scope and size of a particular nursery operation.

STRUCTURES/LANDSCAPE

Describe the immediate landscape in relation to the manmade structures on site. Do these plants serve the function to which they are best suited? Are deciduous trees located in the south quadrant? Are the windbreaks complete barriers?

STRUCTURES/LABOR

Describe daily work routines which relate to manmade structures. Does the layout of a particular structure help to facilitate the work which takes place in or around that structure?

STRUCTURES/MAINTENANCE

Describe the extent of maintenance required on all structures. Do any structures require excessive or repetitious repairs on a regular basis?

STRUCTURES/TRANSPORTATION

Describe the methods used to transport materials to and from structures. Do the structures allow vehicles to move freely about?

STRUCTURES/LAYOUT

Describe daily work routines in relation to the layout of structures on the site. Are structures located so as to reduce wasted labor and transport time? Are storage sheds centrally located?

LANDSCAPE/LABOR

Do the plants used for energy conservation in your operation require minimal or excessive attention? Describe the amounts of labor and materials required to maintain them.

LANDSCAPE/MAINTENANCE

Are the plants which have been used in your operation healthy and growing? Plants should be selected which not only perform a function in terms of conservation, but also are hearty and well adapted to the conditions of a particular site.

LANDSCAPE/TRANSPORTATION

Are plantings and road systems correctly separated from one another? A valuable shade tree can easily be destroyed by heavy equipment which will compact soil around root systems.

LANDSCAPE/LAYOUT

Are plants which are used for climate control suited to the operations and work of each area? For instance, evergreen windbreaks will work for most all structures. Large deciduous trees, on the other hand, may shade greenhouses such that insufficient light is available for growing certain plant materials.

LABOR/MAINTENANCE

Describe the areas in which labor is most intensive. Do workers spend more time in maintenance of facilities or in maintenance of nursery stock?

LABOR/TRANSPORTATION

Are transportation methods suited to the size of your operation and to the needs of your labor force?

LABOR/LAYOUT

Are the facilities oriented to provide specialized areas of your work? For instance, storage buildings should be located near work areas.

MAINTENANCE/TRANSPORTATION

Would modifications in transportation of labor and materials improve the efficiency of your operation?

TRANSPORTATION/LAYOUT

Does the layout of your operation keep the need for mechanical transportation to a minimum?

Exercises

OUTLINE FOR SITE EXERCISES

This set of instructions and the corresponding maps can be used as exercises for any or all sections of this book.

1. "The Core Course"
2. "Landscaping for Conservation"
3. "Energy Efficient Greenhouses"
4. "Nursery Design and Operation for Energy Conservation"

The maps which are included with these instructions are at three separate scales: the site maps are at the scale of 1"=50', the site analysis maps are at 1"=100', and the offsite features map is at 1"=200' The maps describe an actual 54.8 acre site.

TO THE INSTRUCTOR:

(1) The instructor should determine whether a smaller parcel of land (sub-site) within the 54.8 acre site should be selected for all students to work from or whether the selection of a sub-site will be left to the individual based upon the size and scope of project which he/she wishes to undertake. Students interested in pursuing nursery operations will need a larger site with which to work, while students interested in landscape or attached greenhouses will be dealing with a residential size lot.

(2) The instructor should decide whether the students will work individually, collectively, or a combination of both.

(3) The instructor should set a schedule for students to follow in terms of time vs. process.

(4) The instructor should decide areas of emphasis based upon class interest and areas which he/she feels are in need of special attention.

(5) Students must decide the type (nursery, greenhouse or landscape) of project which they wish to undertake. Students should decide on names for their projects.

(6) Each student or group of students will add to their respective site(s) an existing dwelling (house) before beginning the design process.

LANDSCAPE DESIGN FOR ENERGY CONSERVATION

OBJECTIVES

a. Preliminary analysis of the site and existing conditions:
   1. Off-site Features Analysis
   2. Slope Analysis
   3. Vegetative Analysis
   4. Soils Analysis
   5. Surface Drainage Analysis
   6. Solar Analysis
   7. Wind Analysis
   8. Architectural Analysis

b. Siting of the building onto the site with respect to:
   1. Landforms
   2. Vegetation
   3. Solar Energy
   4. Drainage

c. Conceptual master plan for the development of an Energy Efficient Landscape Design.

d. Preservation of the actual character of the land.

e. Integration of the site and structure so as to enhance the performance and quality of both.

f. Achieve a high aesthetic value as an element on the land.

g. Design to supplement summer cooling/winter heating demands.

GREENHOUSE DESIGN FOR ENERGY EFFICIENCY

OBJECTIVES

a. Preliminary analysis of the site and existing conditions:
    1. Off-site Features Analysis
    2. Slope Analysis
    3. Vegetation Analysis
    4. Soils Analysis
    5. Surface Drainage Analysis
    6. Solar Analysis
    7. Wind Analysis
    8. Architectural Analysis

b. Siting of the building onto the site with respect to:
    1. Landforms
    2. Vegetation
    3. Solar Energy
    4. Drainage

c. Conceptual plan for the design of an Energy Efficient Greenhouse.

d. Preservation of the natural character of the site.

e. Integration of the greenhouse to the existing dwelling so as to enhance the performance and quality of both.

f. Achieving high aesthetic value as an element on the land.

g. Design to supplement summer cooling/winter heating demands.

NURSERY DESIGN FOR ENERGY CONSERVATION

OBJECTIVES

a. Preliminary analysis of the site and existing conditions:
   1. Off-site Features Analysis
   2. Slope Analysis
   3. Vegetation Analysis
   4. Soils Analysis
   5. Surface Drainage Analysis
   6. Solar Analysis
   7. Wind Analysis
   8. Architectural Analysis

b. Siting of the building onto the site with respect to:
   1. Landforms
   2. Vegetation
   3. Solar Energy
   4. Drainage

c. Conceptual master plan for the design of an Energy Efficient Nursery Operation.

d. Preservation of the natural character of the site.

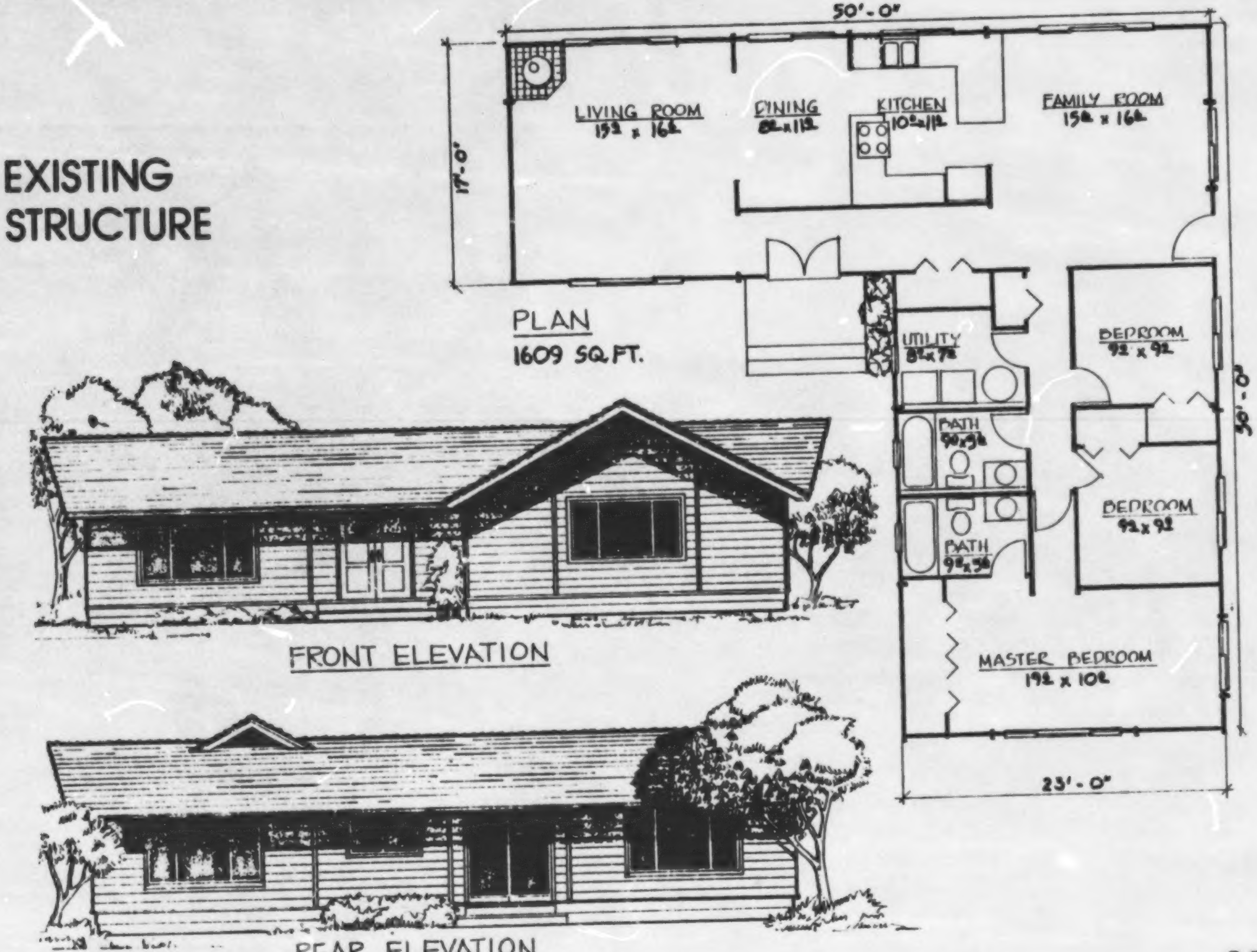
e. Intergration of structures and site so as to enhance the performance and operation of the facility.

f. Conceptual layout for efficient use of labor, materials and energy.

g. Aesthetic value as an element on the land.

h. Design to supplement summer cooling/winter heating demands.

EXISTING STRUCTURE


50'-0"
17'-0"
30'-0"
23'-0"
LIVING ROOM
15^{2} x 16^{6}
DINING
8^{2} x 11^{2}
KITCHEN
10^{0} x 11^{2}
FAMILY ROOM
15^{6} x 16^{6}
UTILITY
8^{6} x 7^{6}
BATH
9^{0} x 5^{6}
BATH
9^{0} x 5^{6}
BEDROOM
9^{2} x 9^{2}
BEDROOM
9^{2} x 9^{2}
MASTER BEDROOM
19^{2} x 10^{6}

PLAN
1609 SQ. FT.

FRONT ELEVATION

REAR ELEVATION

7 MAPS DELETED DUE TO OVERSIZE.